GEOLOGIC SETTING AND ORIGIN OF THE GROUSE CREEK PLUTON BOX ELDER COUNTY, UTAH

by

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ABSTRACT

The southern portion of the Grouse Creek Mountains, located in northwest Utah, consists of about 6000 feet of sedimentary rocks. The stratigraphic column is made up of 1000 feet of Proterozoic phyllites, limestone, dolomite and quartzite; 250 feet of the Ordovician(?) Pogonip(?) formation and 450 feet of the Eureka(?) quartzite; 350 feet of the Devonian Simonson formation and in excess of 1500 feet of the Guilmette limestone; 800 feet of the Mississippian(?)-Pennsylvanian(?) Chainman-Diamond Peak(?) formation; 1000 feet of the Pennsylvanian-Permian Strathearn(?) formation; and more than 1000 feet of the Triassic Thaynes(?) formation. Pliocene sedimentary and volcanic rocks of the Salt Lake formation and an apparently local conglomeratic formation mantle the foothills of the range. The sedimentary rocks have the structure of a major horst composed of flexed sediments broken into numerous fault blocks. Thrust faulting has played a minor role in the evolution of the structure.

An irregularly shaped Tertiary(?) granitic pluton appears to transect the structure of the sedimentary rocks. However, the alignment of the borders of the pluton with major faults in the sediments suggests that preexisting faults partly governed the position

of its borders. Its formation was essentially passive since the sedimentary rocks are not domed in the vicinity of the pluton.

The pluton has an exposed area of 10-1/4 square miles and a probable total area of 15 square miles. It is composed of quartz monzonite (93%) and quartz diorite (7%), and within these major phases minor variants can be recognized which range in composition from leucogranite to meladiorite. Part of the quartz monzonite has been hydrothermally altered with the formation of veins of quartz and pyrite, but without the formation of economic minerals deposits. Quartz diorite, which occurs on the border of the pluton, has an aureole of alteration composed of chloritic quartz diorite in which scheelite is locally present in economic amounts. There is a wide range in textures in the pluton and an unusual textural feature, designated as the "granitic intergranular," occurs principally near the borders of the quartz monzonite but is also found within it.

Interpretative evidence favoring the magmatic origin of the pluton is not evident. The border textures and structures suggest that metasomatism has been an important process in forming the pluton. The quartz diorite is identified as a basic front. The writer concludes that the pluton was probably formed by replacement.

INTRODUCTION

The writer is interested in the origin of granite, and from preliminary examination the pluton of the southern Grouse Creek Mountains seemed to offer a good opportunity for research in this problem. It is young (Tertiary ?) and has not been greatly effected by metamorphism or by structural disturbance since its formation. Furthermore, it is little complicated by associated post-emplacement effects such as ore deposits or pegmatites.

The Grouse Creek stock is one of 400 or more generally similar granitic bodies which crop out in the Basin and Range province of the United States (Stringham (1958)). Since most of these are relatively young and more or less of the same age (Cretaceous to Miocene) it is expected that the features they exhibit collectively may be significant in deducing the origin of granite.

In the course of the study the bedrock geology of the surrounding sedimentary rock was determined in order to establish the geologic setting of the pluton. Since the Grouse Creek Mountains lie in a relatively little studied region of the Basin and Range province, it is hoped that this paper will contribute to a better understanding of the geologic history and the economic potential of the region.

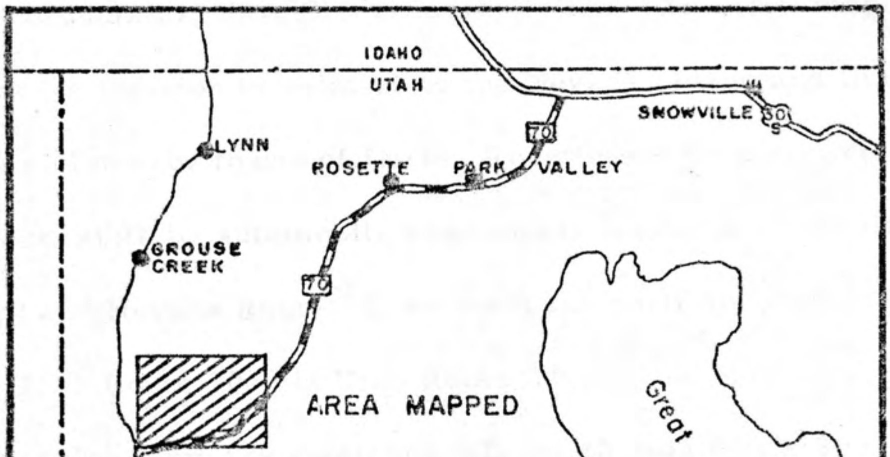

FIGURE I

INDEX MAP

SHOWING LOCATION OF MAPPED AREA

Location, Access and Culture

The Grouse Creek pluton is exposed in the southern end of the Grouse Creek Mountains, Box Elder County, Utah. An index map (Fig. 1) shows its location in relation to the Nevada, Idaho and Utah state borders and nearby towns of Lucin, Rosette and Grouse Creek. It is easily accessible by automobile road either from the south via U.S. Route 40 and Nevada Route 30, or from the north through Snowville on U. S. Route 30s via Utah Route 70.

Approaching from the south one follows Nevada Route 30 to the state border where the road designation changes to Utah Route 70. Route 70 is followed northward to its junction with the county road leading to the town of Grouse Creek. From the junction with the Grouse Creek road, which is conspicuously marked by signs, it is one-quarter mile eastward by road to the southwest corner of Sec. 11, T. 8 N., R. 18 W., the southwesternmost point of the area mapped (Plate I). Approaching from the north one may follow Route 70 to the county road leading to the Rose Bud Ranch and marked by a sign. The county road enters the mapped area in Sec. 13, T. 10 N., R. 16 W. Maintenance of this road past the ranch is relatively poor and ordinary passenger cars are better taken to the southern junction of the county road with Route 70, located in Sec. 11, T. 8 N., R. 17 W., and marked at present by a crude sign reading "Magnitude Mine." Plate I shows the roads within the mapped area passable by automobile, but those designated as "poor automobile roads" may be locally impassable to vehicles of long wheel base or low centers. Within the mapped area there are numerous roads and trails built by ranchers, sheepherders and miners. These are generally passable to vehicles equipped with four-wheel drive but often terminate abruptly at a salt lick, camp site or prospect pit.

There are two cabins in the area, at the "A. M. W." and Magnitude mines, located near springs where potable water is sometimes available in the spring season. However, the visitor to the area is advised to bring enough water to outlast his stay since the springs are often contaminated and require cleaning. Drinking water is always available at the town of Lucin and at Rabbit Springs, three miles south of the southernmost rhyolite knoll shown on Plate I.

Field and Laboratory Work and Acknowledgments

The field work upon which the present study is based was conducted during the field season of 1956 and parts of the field seasons of 1957 and 1958. The field data were analyzed in the laboratories of the University of Utah.

The writer is particularly grateful to Prof. B. Stringham, who spent a day in the field examining the plutonic rocks in the southern

Grouse Creek Mountains. His suggestions, both in the field and in the course of informal discussions at the University of Utah, were helpful in guiding this study. Mr. F. Schaeffer spent two days in the field examining the sedimentary rocks, and he pointed out features which helped to establish the stratigraphic relations in the area. Discussions with Prof. A. J. Eardley were helpful in resolving certain problems relating to the structure of the area studied.

This study was facilitated by the help of Mr. and Mrs. R. Wheatley, residents in the southern Grouse Creek Mountains, who assisted the writer with numerous geographic problems. Mr. U. Puello kindly permitted the use of his cabin at the Magnitude mine. The Standard Oil Company of California made available a base map which was used during the early stages of mapping.

Fossil identifications indispensable to this study were made by Prof. W. L. Stokes, who identified the Triassic fauna, by Mr. G. Steele, who identified the microfauna in a suite of samples from Bovine Mountain, by Dr. D. Taylor, who identified the Cenozoic moluska found south of the Magnitude mine, and by Mr. R. Waite, who identified the corals found in the Silurian formation.

The writer is also indebted to Profs. B. Stringham, A. J. Eardley, W. L. Stokes, M. Erickson and J. Whelan for their helpful suggestions regarding the manuscript.

Climate, Flora, Fauna and Exposures

The office of the State Climatologist of Utah reports that the town of Lucin (see Fig. 1) usually receives less than six inches of precipitation per year, while Grouse Creek and Park Valley receive between ten and eleven inches. Undoubtedly the area mapped receives an average annual rainfall between these limits.

Although climatologically the Grouse Creek Mountains are in an arid region, rainfall is sufficient to support a relatively dense plant cover. On lower elevations are found sage and desert grasses, on intermediate elevations jumiper occurs with sage, and on the highest protected slopes are forests of pinon pine, juniper and mountain mahogany. The fauna commonly encountered includes jack rabbits, cottontail rabbits, deer, eagles, hawks, magpies, and small lizards.

The distribution of vegetation is controlled not only by elevation but also by geologic structure, composition of bedrock and other factors. In general, plant cover is heaviest on north and west-facing slopes, on gentle slopes and on limestone terranes. Consequently the number and quality of outcrops exposed through the cover of eluvium and vegetation is, from the point of view of the geologist, erratic and ranges from excellent to poor. On the east side of Citadel Peak 90% of the granite is exposed on steep slopes. On the west side limestone and dolomite crop out on only 5% of the gentle slope. About 10% of the area of the southern Grouse Creek Mountains is exposed as outcrops of bedrock.

There is some evidence that the climate has become more arid during the past 50 years. Mr. U. Puello reports that in 1905 and for several years thereafter wheat was grown in the meadow south of the Magnitude mine. Mr. R. Wheatley, however, said in 1957 that he had found it impossible since 1946 to grow any variety of domestic plant in the same meadow without irrigation, that sufficient water for a garden large enough to supply the wants of two people was unavailable, and that wheat could no longer be grown.

Previous Geologic Work

King (1878) published a very general description of Box Elder County, and Hague (1877) also in very general terms, described the area of the southern Grouse Creek Mountains under the heading of the Raft River Range. Butler (1920) published a short description of the whole range in connection with his study of the ore deposits of Utah. The account of King is little more than a reference to the existence of the range. Hague says that Carboniferous strata have apparently been domed by an intrusive body, a generalization not substantiated by the present study. Butler's description of the southern part of the range is taken from Hague, although he mentions in addition the diversity in the composition of the pluton. Crawford _et al_ (1948) provide a brief description of the northern part of the range. Unfortunately, the maps referred to in their note were not completed, although some field work appears to have been done. Hess and Larsen (1922) describe the tungsten deposits with particular emphasis on mineralogy, while Kerr (1946) refers to the tungsten deposits in the course of his larger study of the tungsten mineralization in the United States.

Geographic and Geologic Setting

The Grouse Creek stock is one of many which crop out in the Basin and range province. Because of the linear pattern developed by the tectonic activity which produced the province, the granites are, in a gross way, distributed irregularly along north-trending lines which cross the region. (This pattern may be more apparent than real since the bedrock which floors the basins of the province is not observable.) The Grouse Creek stock is located on one of these lines. To the north, also in the Grouse Creek Mountains but separated from the Grouse Creek stock by about seven miles of sedimentary and metamorphic rock, is the Muddy Creek pluton. In the Pilot Range about twenty-five miles to the south is the Pilot stock. Separating the three stock along the trend of their outcrop are more or less folded and faulted Paleozoic and Precambrian sedimentary rocks and areas of younger Cenozoic alluvium, lake beds and volcanics. To the west the nearest granite is exposed near the Delno mine, about thirty miles from the Grouse Creek stock. To the east the nearest exposed granitic rock is found in the Newfoundland Range, separated from the Grouse Creek Mountains by twenty-five miles of lake sediments.

The Grouse Creek Mountains are a south-trending extension of the Raft River Range, which is a prominent east-trending range along the northwestern border of the state of Utah. Between the Raft River Range and the Grouse Creek Range there is a minor topographic break near the town of Lynn. On the East the mountains are bordered by a broad valley, the northern part of which is composed of interbedded alluvial and lake sediments and limestones and basalt flows, the southern part of lake sediments. The mountains are bordered on the south by lake and alluvial sediments broken by patches and ridges of Tertiary volcanic rocks of rhyolitic composition. On the west the Grouse Creek Mountains are separated from the southern Goose Creek Mountains, composed largely of Teritiary volcanics, by the valley of Grouse Creek, which is floored by alluvium and rhyolitic volcanic rocks.

The northern portion of the Grouse Creek Mountains is made up largely of Precambrian metamorphic rocks and granite. Crawford <u>et al</u>

(1948) describe the northern Grouse Creek Mountains as consisting of "a great thickness of pre-Cambrian metamorphics, predominantly granitic gneisses, amphibolite, and quartz-mica schists."

GEOMORPHOLOGY

General Form

In plan view the Grouse Creek Mountains consist of a south-trending principal range to which Bovine Mountain is a southeast-trending satellite. This form is incompletely suggested by Plate I since the mapped area extends only four miles north of Bovine Mountain. The borders of the southern Grouse Creek Mountains are sinuous and embayed and inselberge are isolated as much as three miles to the east of the main range.

The range presents an asymmetrical transverse profile. From Plate I it is seen that from North Rocky Pass to the western-most foothills (represented by the westernmost exposure of rock younger than Quarternary) it is about six miles. From North Rocky Pass to the easternmost foothills it is about three miles. The eastern front of the range is steeper than the western. It can also be seen that Bovine Mountain is steeper on the east than on the West since from the summit it is three miles to Emigrant Wash on the west but only 1-1/2 miles to the alluvium on the east.

Scarps

Scarps which are present are confined to the east side of the range. The most prominent scarp borders the Paleozoic sediments on the southeast flank of Bovine Mountain. It extends discontinuously for 2-1/2 miles from near the S. W. corner of Section 33 to near the S. W. corner of Section 22, T. 9 N., R. 16 W. Plate I shows that the scarp marks a geological hiatus between the Strathearn formation and beds whose formational lithologies could not be recognized. The other scarp crosses most of Section 14, T. 10 N., R. 16 W., and continues for about one mile outside the area mapped. Both scarps trend N. 15° E.

Pediments

On the west side of the range, that portion of the foothills lying northwest of a line drawn from Section 7, T. 9 N., R. 17 W., to Section 23, T. 10 N., R. 17 W., shows a tendency toward concordance in elevation of the summits of the ridges. This area is made up of poorly cemented conglomerate and tuff and the surface is interpreted as the remains of an immaturely developed pediment.

On the east side of the range is a better developed but smaller pediment north of Bovine Mountain and southeast of the chain of inselberge.

The County road bisects the area. The pediment is cut in granite and granitic debris. Present day streams are cutting into alluvial deposits 100 to 150 feet below the surface of the pediment.

The inselberge which border the eastern pediment form a chain which trends northeast from the S. W. corner of T. 10 N., R. 16 W. They are rounded and subdued but contrast in relief with the pediment on the southeast and the alluvial meadows on the northwest.

Structure

The Salt Lake and Tertiary unidentified formations on the west side of the range dip gently, in most places less than 15°, toward the west and northwest. On the south end of the range and southwest of Bovine Mountain the dip of the beds is generally gently southward but reversals in dip are observed locally. A particularly steep dip 20° northeast is found in the unidentified formation near the S. W. corner of Section 25, T. 9 N., R. 17 W. However, where the dip is visible in the same formation one mile to the north it is 5° east, suggesting that the attitude of the formation has been modified by local faulting. The Salt Lake beds which lie south of State Route 70 dip gently away from the range. The alluvium into which streams are cutting north of Bovine Mountain is essentially horizontal.

Lake Features

Lake Bonneville has left an impressive and scarsely dissected array of lacustrian features. Beaches, bars, spits, tombolos, wave-built and wave-cut terraces and wave-cut cliffs are particularly conspicuous on the east and south side of the range. No attempt was made to map these features. However, it was noted that the highest bench of the old lake which is cut into the Salt Lake conglomerates in the vicinity of Section 36 T. 9 N., R. 17 W., appears when viewed from the south to be tilted slightly to the east. Possibly, therefore, there may be direct evidence of slight recent diastrophism in the southern Grouse Creek Mountains.

Conclusions

The asymmetry of the range and the distribution and attitude of the Salt Lake and Tertiary unidentified formations suggest that the Grouse Creek Mountains are block mountains tilted westward. The asymmetry of Bovine Mountain further suggests that faulting has been along more than one fault or fault zone. The chain of inselberg are interpreted as a fault splinter common to block mountains (Lobeck (1933), p. 559).

The presence of the Tertiary unidentified conglomeratic formation and the pediment on the west which is in part cut into it suggest that uplift has been spasmotic and extends back to Pliocene time. The alluvial debris which fills valleys in the eastern pediment and is now being eroded also suggests spasmotic uplift. Although it is recognized that the change in stream regimen from degradation to aggradation and back to degradation can be accomplished by means other than diastrophism, the evidence of the eastern pediment is interpreted to indicate oscillations in the level of the mountains relative to local base level during Quaternary time. The fault scarp on the southeast side of Bovine Mountain, since it is hardly dissected by erosion, implies Quarternary faulting.

The sinuous outline of the range, the isolation of the inselberge and the alluvial embayments indicate that the southern Grouse Creek Mountains are block mountains in the stage of late maturity of the geomorphological cycle.

SEDIMENTARY AND VOLCANIC ROCKS

Introduction

Metamorphic and sedimentary rocks of Proterozoic, Ordovician(?) Silurian, Devonian, Mississippian(?), Pennsylvanian, Permian, Triassic, Tertiary and Quarternary age are exposed in the southern Grouse Creek Mountains. Fossils are not common but the stratigraphic units of the area can be correlated with those in nearby ranges partly by comparison of lithologic character and lithologic sequence. Repitition and omission of strata due to faulting is so extensive that it is not possible to measure the total thickness of even one formation, and the figures given are minimum estimated thicknesses. Volcanic rocks form a part of the Tertairy system.

Proterozoic Era

Phyllite Unit

On the northeast side of Bovine Mountain, in Sections 21, 22, 27 and 28, T. 9 N., R. 16 W., is a sequence of phyllites, quartzites and limestones dipping at 35° to 40° southwest and forming a jagged but not precipitous hill.

Typically the formation is of phyllite composed of quartz in grains 0. 04-0. 08 mm in diameter and calcite in grains 0. 15 to 0. 3 mm. Layers of quartz alternate with layers of calcite. Carbonaceous material is generally found as a thin coating around the quartz grains. Sufficient sericite is associated with the quartz to give hand specimens a distinct sheen on the planes of schistosity, but it is not conspicuous microscopically. Associated with the phillites are beds of blue to black, rarely brown limestone and silicified limestone which contain beds of shaley or phillitic quartzite. These occur in beds up 150 feet thick between phyllite members. Brecciation is intense on some horizons and it seems likely that the beds have been repeated by faulting parallel to the strike.

The exposed thickness of the formation is about 1, 000 feet. It does not crop out in neighboring areas which have been mapped but may belong to the metamorphic complex which makes up the northern Grouse Creek Mountains. It is similar in lithology to some of the Proterozoic rocks in the Raft River Range (Felix (1956)) and of the southern end of the Promontory Range (Olsen (1956)), and is presumably Proterozoic in age.

Quartzite unit

Situated near the northeast corner of the map, in Sections 13 and 14, T. 10 N., R. 16 W., there is an area of about 1/2 square mile where quartzite beds dip gently northwest. The rock is white, dense and glassy. Near the middle of the unit there are two beds, each 2 inches thick, of crumpled biotite. The biotite beds are separated from each other by about 15 feet stratigraphically. The whole exposure is about 75 feet thick and on lithologic grounds is referred to the Proterozoic undifferentiated.

Ordovician(?) System

General Statement

Two formations here are assigned to the Ordovician system on the basis of their stratigraphic position and lithologic appearance. No fossils have been observed or reported in either.

Pogonip(?) Formation

Cropping out at the summit of Citadel Peak is a thin-bedded and very sandy limestone which dips northward toward the pluton at a high angle. The bed is much crumpled, folded, faulted and slightly metamorphosed. Its color over-all is light brown, and it is composed of layers 1/4 to 3/4-inch thick of very well oriented elongate calcite grains about 0.35 mm long among which are sparsely scattered angular to rounded quartz grains 0.02 mm in diameter and subhedral grains of dioposide about 0.06 mm in length. Separating these calcareous layers are sandy beds 1/8 to 1/2-inch thick composed of quartz and calcite grains in about equal amounts in which crystals of diopside up to several mm long occur. The diopside cyrstals poikilitically enclosed both quartz and calcite grains. Folding, faulting, and crumpling make exact measurements impossible, but the maximum exposed thickness is about 110 feet. The lower contact is not exposed; the upper contact is sharp and conformable in attitude with the overlying quartzite formation. No fossils were found in this unit.

To the west of the pluton which crops out in Willow Wash (in Section 10, T. 9 N., R. 17 W.) underlying a quartzite formation which borders the pluton is a unit of thin to medium-bedded sandy limestone. It is folded but not crumpled and has an exposed thickness of about 150 feet. It is apparently devoid of fossils. This unit is also referred to the Pogonip(?) formation on the basis of lithology and stratigraphic position.

The Pogonip(?) formation in the Grouse Creek Mountains resembles the upper portion of the Garden City formation described by Anderson (1957) in the northern Silver Island Mountains, and was examined in the field by Mr. Fred E. Schaeffer, who concluded that the unit probably represents part of the Pogonip formation of Hintze and Webb (1950).

Eureka(?) Quartzite

The Eureka(?) quartzite crops out on the western and southwestern margins of the pluton in the vicinity of Willow Wash. An exposure of quartzite at the southeast end of Bovine Mountain is questionably referred to the Eureka(?) quartzite. It is usually found dipping steeply but it has been observed to be only moderately folded. West of Citadel Peak and in the vicinity of the Magnitude mine it is broken by numerous faults. The quartzite upholds the steep slopes of Citadel Peak but does not form cliffs; near the Magnitude mine it forms rounded hills.

Typically the Eureka(?) is composed of white, glassy quartzite which may or may not show indefinite streaks of light blue-gray parallel to the bedding. At some exposures it has a delicate orange hue. Specimens of the quartzite collected more than 200 feet from the border of the pluton are seen to consist of interlocking allotrimorphic grains of quartz 0.5 to 0.8 mm in diameter, a few muscovite flakes, and rare cubes of limonite after pyrite. Nearer the pluton the Eureka(?) contains feldspar, biotite and chlorite, and locally its texture is granulitic. Neither calcite beds nor calcite veins were found in the unit, although quartz veins up to 1/2-inch wide are common near its contact with the pluton.

The Eureka(?) quartzite has a maximum exposed thickness of 450 feet. Its lower contact is lithologically abrupt and conformable with the underlying Pogonip(?) formation. Its upper sedimentary contact is not exposed. Where the quartzite borders the pluton its contact may be sharp or graditional. Near the Magnitude mine the zone of transition between the quartzite and the pluton is as much as 50 feet broad; in the vicinity of Citadel Peak the contact is generally sharp but locally zones of transition up to two feet broad may be found.

No fossils were found in the quartzite. As with the underlying formation, the correlation of the Eureka(?) quartzite of the southern Grouse Creek Mountains with the Eureka quartzite of neighboring ranges (Paddock (1956) and Anderson (1957)) is made principally on the basis of its lithology and stratigraphic position.

Silurian System

Laketown Dolomite

The Laketown dolomite crops out at the southeast margin of Bovine Mountain. In the one outcrop where it is exposed near State Route 70, in Section 34, T. 9 N., R. 16 W., it dips at 80° to the northeast, forming a rounded knoll.

The Laketown dolomite consists of massive, light gray dolomite in grains between 0.5 and 1.0 mm in diameter. Two hundred feet stratigraphically above the bottom of the outcrop is a black dolomite member 25 feet thick, and near the top are three lenses of black dolomite three to six feet thick. Except in color the black dolomite is similar to the light gray. Throughout the formation are lenses up to four inches thick of brown quartzite which are separated from each other stratigraphically by two to ten feet and which appear to be slightly less abundant in the black members of the formation than in the light gray ones. The dolomite weathers to a very rough, jagged surface without discoloration, whereas the quartzite lenses are generally covered with dark brown to black desert varnish.

The thickness of the dolomite here is about 350 feet and neither the upper nor the lower contacts are exposed.

Silicified fossils may be found sparsely distributed in the lower portion of the exposure. Crinoid columnals up to 1-1/2 inches long, 1/2-inch in diameter are the most abundant. Three corals were found, two of which were identified by Mr. Roy Waite, of Shell Oil Company, as *Favosites* sp., one as *Halysites* sp. They are typical of the Laketown dolomite of northwestern Utah.

Also thought to be part of the Laketown dolomite are beds exposed as fault slivers at the southeast end of Bovine Mountain (see Plate I). The correlation is much less satisfactory than is that of the outcrop described above since no fossils were found. However, the beds are of dolomite which is largely light gray or brown and which enclose beds of black dolomite three to ten feet thick.

Devonian System

Simonson Formation

The Simonson formation is exposed in a discontinuous belt around the north and east border of the tongue of plutonic rock whose principal exposures are in the valley of Willow Wash. On the east side of the tongue of plutonic rock, in Sections 12 and 13, T. 9 N., R. 17 W., the Simonson formation dips toward the pluton. North of the tongue of plutonic rock it dips away from the pluton. The strike of the formation is, however, generally parallel to the border of the pluton. A very small outcrop of dolomite in Section 21, T. 10 N., R. 16 W., is questionably referred to the Simonson formation on the basis of its lithology and stratigraphic position.

The best exposure of the Simonson formation is at the Compressor mine. Here it is composed of white to light cream-colored dolomite except near its contact with the pluton, where it is pink to red. The red coloration which it exhibits in a zone two to ten feet wide contiguous with the pluton is caused by hematite in very thin layers around the dolomite grains. The dolomite grains of which the unit is composed are equant, about 0.3 mm in diameter, and do not change in size as one approaches the plutonic border. The coherence of the dolomite, however, changes from loose and sugary in the zone contiguous with the pluton to dense away from the pluton. In the vicinity of a quartz blowout and of an apophysis of the pluton in the formation it is white and dense. The unit is about 100 feet thick.

Along the west wall of Emigrant Wash the Simonson formation is also composed of dolomite, medium-bedded and light gray in color. It does not assume the red coloration along the contact with the pluton which is developed at the Compressor mine, but is bleached and silicified near the contact. The maximum exposed thickness in this locality is between 150 and 200 feet.

On the north wall of Willow Wash, to the west of the Compressor prospect, the Simonson formation presents two lithologic aspects. That part of the formation which is conformable with the overlying Gullmette formation resembles the dolomite unit at the Compressor mine, i. e., is a dense, very light cream-colored dolomite. Separated by a fault from the dense dolomite unit is a poorly exposed dolomitic unit the thickness of which was measured by the pace and compass method.

Unit		Feet
9.	Dolomite, white to light gray, massive	25
8.	Limestone, gray, veined with brown calcite which in some places forms a thin-walled boxwork. Tremolite pods in lower part.	40
7.	Limestone, gray, massive	50
6.	Limestone, gray, massive, containing isolated globular masses and irregular veins of brown calcite	10
5.	Dolomite, mottled gray and blue, massive	125

Unit		Feet
4.	Limestone, light tan, granular, occurs as lens	15
3.	Limestone, mottled gray and blue, massive	25
2.	Dolomite, light gray, highly jointed, massive	140
1.	Dolomite, white sugary, homogeneous, massive	75
	Total	505

The lower contact of this unit is with the pluton. The upper contact is with a fault. No fossils were found.

Correlation of the above described formation with the Simonson formation of northern Silver Island (Anderson (1957)) is made entirely on the basis of lithologic similarities (in the case of the measured unit) and stratigraphic position below the Guilmette formation.

Guilmette Formation

The Guilmette formation upholds the crest of the southern Grouse Creek Mountains north of Rocky Pass, is exposed as a fault block south of Citadel Peak, crops out near the A and W Mine and forms a belt four miles long and up to two miles wide bordering Bovine Mountain on its west side. It also crops out at the south end of Bovine Mountain along the boundary between T. 8 and 9 N., and forms a chain of inselberge trending northeast on the east side of the Grouse Creek range to the east of North Rocky Pass (see Plate I).

The Guilmette formation is broken into numerous fault blocks within which dips are generally observed to be steep. In two localities it is folded and overturned. At the east of the head of Emigrant Wash in Section 7, T. 9 N., R. 16 W., and in the S. E. 1/4 of Sec. 13, T. 9 N., R. 17 W., the beds can be observed to turn over as one procedes normal to the strike. In several places Guilmette beds are vertical, and in the center of Sec. 13, T. 9 N., R. 17 W., horizontal Guilmette limestone can be seen resting on vertical Guilmette limestone.

The Guilmette formation forms rugged, jagged slopes when eroded on an anti-dip surface. In several localities it forms escarpments up to 20 feet high. When eroded on a dip surface it is more likely to form rounded slopes. On aerial photographs and in the field it can often be recognized by its tendency to support a heavier plant cover than the formations with which it is in contact.

More than 95% of the Guilmette formation is composed of medium-bedded to massive uniformly blue-gray limestone. Highly irregular and discontinuous quartzitic layers up to two inches thick may be found along the bedding planes of the limestone, generally separated stratigraphically from each other by six inches to three or four feet. Occasionally limestone beds up to fifty feet thick may be found to lack the sandy layers. In a very few places sandy beds up to six feet thick may exceed in volume the limey beds.

The Guilmette limestone is generally composed of calcite in an interlocking structure of grains which range in diameter from 3.0 to 0.2 mm. The average grain size of the limestone is 0.3 mm, but the fragments of fossils which the formation contains are generally re-crystallized into grains larger than one millimeter in diameter. In thin sections one sees, in addition to the calcite, small lenses up to three or four millimeters long composed of quartz grains 0.1 mm in diameter. These are, presumably, the microscopic cognates of the quartzite layers. Stringers or veinlets of calcite, usually less than 15 mm thick, are abundant in the limestone. Quartz stingers are rare. By many tests with dilute hydrochloric acid it is possible to find irregular patches, no more than 100 square feet in area, of dolomitic limestone. These have no relation to the bedding of the formation and are regarded as a minor manifestation of the weak metamorphism which has effected parts of the southern Grouse Creek Mountains. Chert lenses and nodules, in the place of quartzite lenses, occur in the Guilmette on the east side of Bovine Mountain.

The minimum exposed thickness of the Guilmette formation is 1500 feet. Detailed stratigraphic study might reveal that a consider-ably greater thickness is present.

The lower boundary of the Cuilmette formation has been placed at the contact between the gray limestone and the cream-colored dolomite which can be seen near the Compressor mine. Here the contact is sharp, although no angular discordance can be observed. About seventy-five stratigraphic feet above the contact is a bed eight feet thick of gray dolomite. With this exception, and the exception of the small irregular patches of dolomite already mentioned, the Guilmette formation is composed of limestone and sandstone and the lower contact could easily be drawn chemically, although in this case a sharp color contrast also exists.

In Bovine Mountain the upper lithologic boundary of the formation is less sharp than the lower. Within 100 feet of the top limestone gives way to sandstone and shale, and the upper contact has been drawn where limestone beds are less abundant than shale and sandstone, or, more properly, than meta-argillite and quartzite. No unconformity is visible lithologically nor paleontologically although in neighboring ranges an unconformity is recognized. At North Rocky Pass the upper contact of the Guilmette formation is concordant in attitude but lithologically abrupt.

It is unusual to find an exposure of Guilmette limestone having an area of more than 1000 square feet in which a fossil cannot be found. Fragments of crinoid stems are the most characteristic fossils of the Guilmette. They are generally seen as complete but separated disks ranging between 1.5 and 10 mm in diameter composed of white clacite.

So abundant are these fragments that they serve to identify Guilmette float in detrital deposits several miles removed from the nearest exposure of the formation. They have not been observed as important constituents of the other formations which make up the southern position of the Grouse Creek Mountains.

The recognizable fossils next in abundance to the crinoids are wormy intergrowths of recrystallized calcite which by their form may be identified as Amphipora. These occur in beds ranging in thickness from four inches to four feet. Less abundant are beds of spherical structures, each sphere between six and 15 inches in diameter and together making a more or less compact colony of spheres five to ten feet in largest dimension. Taken separately, these beds are suggestive of stromotoporoidea, and viewed in conjunction with the Amphipora beds near which they occur this identification is almost certain. In no place, however, has a well preserved lens of stromotoporoidea been found. One of the least ambiguous can be seen near the base of the formation on the south-facing slope to the south of the A & W claim. Here it occurs within several tens of stratigraphic feet of a bed of undoubted Amphipora, and, incidentally, near one of the few localities where the base of the Guilmette formation is exposed.

Near the center of Sec. 18, T. 9 N., R. 16 W., embedded in a large, smooth outcrop of limestone, a recognizable cup coral was observed. Elsewhere indefinite markings, not recognizable as particular species or forms, are suggestive of fossils.

Lacking diagnostic fossils it is not possible to assign a precise age to the Guilmette formation in the Southern Grouse Creek Mountains. It is presumably the same age as the corresponding formation described in the Northern Silver Island Range (Anderson (1957)), namely, Middle to Upper Devonian.

Mississippian(?) and Pennsylvanian(?) Systems

Chainman-Diamond Peak(?) Formation Undifferentiated

Interbedded with the upper portion of the Guilmette formation and lying above it is a sequence of sandy limestones, meta-argillites, sandstones, quartzites and pebble conglomerates. This formation is best exposed in Bovine Mountain, but also crops out at North Rocky Pass and in the chain of inselberge to the east of North Rocky Pass. The unit is generally steeply tilted and in some places is vertical. It forms valleys and gently rounded hills.

The lower part of the Chainman-Diamond Peak(?) formation is different in Bovine Mountain from that exposed at North Rocky Pass and in the chain of inselberge east of North Rocky Pass. In Bovine Mountain it is composed of quartzite and meta-argillite and limestone beds interbedded. The lower boundary of the formation has been placed where clastic material is preponderant over carbonate. There is no angular discordance between the Chainman-Diamond Peak formation and the underlying Guilmette formation, although in nearby areas (Anderson (1957)) and Paddock (1956)) an unconformity exists. Above this sequence is a reddish sandstone of unknown thickness which makes up the bedrock floor of the western portion of Bovine Flat, where it is poorly exposed. Next above the reddish sandstone is another sequence of interbedded limestone, argillite, quartzite and at least two beds of dark brown pebble conglomerate. The pebble conglomerates are distinctive brown strata consisting of elongate to discoidal pebbles in a matrix of fine-grained brown quartzite. The pebbles as seen in one thin section are composed of quartz grains ranging in size from 0.03 to 0.005 mm, accompanied by sericite and hematite. There is no suggestion of a granulitic texture, but some of the inter-pebble quartz appears porphyroblastic, indicating that some recrystallization of the quartz has occurred. Above the pebble conglomerates sandy limestone and sandstone beds alternate with thin beds of argillite. The total thickness of the formation in Bovine Mountain is about 800 feet.

At North Rocky Pass and also in the chain of inselberge east of North Rocky Pass the Chainman-Diamond Peak(?) formation rests apparently concordantly upon the Guilmette formation. However, the basal unit of the Chainman-Diamond Peak(?) formation is a dark brown, massive quartzite lacking pebble conglomerate. The quartzite is about 150 feet thick, and no units above it are exposed. No fossils have been found in the Chainman-Diamond Peak(?) formation either in Bovine Mountain or at North Rocky Pass.

Correlation of the Chainman-Diamond Peak(?) formation of the southern Grouse Creek Mountains with that of the northern Silver Island Mountains is on the basis of lithology and stratigraphic position. In that range Anderson (1957) established on paleontological evidence the Late Mississippian or Early Pennsylvanian age of the Chainman formation and the probable Early Pennsylvanian age of the overlying Diamond Peak formation. The corresponding formation in the southern Grouse Creek Mountains is likewise probably Late Mississippian and/or Early Pennsylvanian.

Pennsylvanian and Permian Systems

Strathearn(?) Formation

Above the Chainman-Diamond Peak(?) formation are interbedded limestones and sandstones. These are exposed only at and to the east of the summit of Bovine Mountain where they form a syncline plunging south, and on the extreme east flank of Bovine Mountain where they dip 40° southwest. The beds from gently rounded slopes at the summit of Bovine Mountain but form cliffs and steep talus slopes on the east side.

The formation is composed of thin to medium-bedded limestone in beds four to twenty feet thick interbedded with sandstone beds one to ten feet thick. The carbonate-clastic ratio is about 5:1. The limestones making up this formation are generally medium blue-black and weather to rusty brown or olive drab. A few beds are resistant to a change in color upon exposure and are blue-black on the weathered surface. They are composed of grains of calcite which rarely exceed 0.5 mm in diameter. Quartz is almost universally present admixed with the calcite. Small calcite stringers up to 1/4-inch in width are not uncommon in the limestones. Typically these occur in swarms, where they may both transect the bedding and be parallel to it. The swarms do not persist along strike more than a few feet and they do not generally have a vertical range of more than one or two feet. Small sandy lenses up to two inches thick occur in the carbonate beds, but are rare.

The sandstone beds of the Strathearn(?) formation are light to dark brown. Occasionally they are limey sands, more generally they are coherant sandstones and quartzites. The grain size, like that of the limestone, does not exceed 0.5 mm. Quartz veins, occasionally up to 1/2-inch in width, are not uncommon in the quartzitic members. Clacite stringers have been observed but are rare.

The lower boundary of the Strathearn(?) formation is placed between the highest meta-argillite of the underlying Chainman-Diamond Peak(?) formation and the lowermost occurrence of fusulinid fossils. These are separated by 50 stratigraphic feet of limestone containing some sandy beds. The boundary is entirely gradational and the contact drawn on Plate I is placed arbitrarily midway between the two features. The upper boundary of the formation has not been recognized in Bovine Mountain. Its exposed thickness is about 1000 feet.

Fusulinids were the only fossils found. They are particularly abundant near the base but occur sparsely distributed in the limestones throughout the vertical extent of the formation.

None were found in sandstone and quartzitic members. It was noticed that fusulinid remains may be found most abundantly in those limestone strata which do not form a brown or drab weathered surface. In the blue-black weathering limestones fossils are occasionally so abundant as to constitute 15% of the rock.

Grant Steele, of the Gulf Geological Laboratory, kindly furnished the following information on fossils from Bovine Mountain: "Most of the specimens were replaced by silica. Only the forms present on the outside of the rock displayed any structure. Because of the poor degree of preservation an exact dating is not possible." He declined to assign specific names to the forms in the suite of rocks sent to him. With the exception of one Schwagerina all specimens belonged to the genus Triticites. Their ages are in a range from high Virgil to lower Wolfcamp according to Steele.

The age and lithology of the formation are comparable to the Strathearn formation in Elko County, Nevada, as described by Dott (1955), and also comparable in lithology to the Oquirrh formation at Gold Hill (Nolan (1935)).

Triassic System

Thaynes(?) Formation

Triassic rocks crop out on the western flank of the range in the vicinity of Rocky Pass Canyon. They are folded into an anticline whose axis trends west and which forms steep but rounded hills with slopes characteristically mantled by sheets of talus fragments. They are also exposed in an isolated outcrop in Sec. 9, T. 9 N., R. 17 W., where they dip 20° west (see Plate I).

The Triassic is composed of brownish and reddish sandy to shaly limestone, limestone, and sandstone, approximately in the ratio 15:4:1. Dolomitic beds are rare. The average grain size of the large dimension alternate stratigraphically with layers of the smaller. Rounded quarts grains of the same dimensions may make up as much as 10% of the rock. The sandy limestones have a similarly banded structure but the grain size lies between the limits 0.5 and 0.1 mm, there is more quartz in the rock and lenses of quartz in grains 0.05 mm in diameter may be seen in thin section. In the westernmost exposures of the Triassic formation chert beds are common. They are, on the average, lenses two feet long and three inches thick, and they contribute distinctive rounded pebbles to the talus slopes. Stringers of calcite are not abundant and stringers of quartz are quite rare. Hematite and limonite are widely distributed in the formation in a minutely comminuted form and give to the weathered rock its characteristic tan and, in some places, chocolate color.

The thickness of the Thaynes(?) formation is about 1200 feet if possible repitition of the beds is neglected. The fault block on the west flank of Citadel Peak consists of about 300 feet of exposed Triassic rock. About 800 feet of Triassic rock is exposed in Rocky Pass Canyon. The outcrop in Sec. 9, T. 9 N., R. 17 W., exposes between 80 and 100 feet of the Thaynes(?) formation. Neither the upper nor the lower contact was found in the area mapped.

Fossils are quite abundant in the formation. William L. Stokes kindly examined the assemblage collected and identified it as that of the Thaynes formation of the Wasatch Range and southeastern Idaho.

He identified:

> <u>Pentacrinus sp.</u>
> <u>Lingula borealus</u>
> <u>Aviculipectin utahensis</u>
> <u>A. desert</u>
> <u>A. occidaneus</u>
> <u>A. disjunctus</u>
> <u>Monotus thaynesigna</u>
> <u>Astartella sp.</u>

The Thaynes formation is of early Triassic age.

Tertiary System

Salt Lake Formation

Surrounding the southern Grouse Creek Mountains on the east, south and west is a series of mudstones, vitric tuffs, rhyolite flows and vitrophyrs. Three units can be recognized in the formation.

<u>Mudstone-vitrophyr member</u>. The lowermost unit of the group crops out in the southern portion of Willow Wash, in isolated outcrops southeast of Bovine Mountain, and in a discontinuous exposure which follows the abandoned Southern Pacific Railroad grade. It can be recognized on aerial photographs and at a distance in the field by its white or light gray outcrops. In the southern portion of Willow Wash it is a well sorted mudstone and contains conglomeratic beds up to one foot thick composed of subangular pebbles of quartzite and limestone up to two inches in diameter. Apparently at the same horizon, one mile to

the east, is very well stratified, white incoherent vitric tuff. The two facies give the impression of interfingering, but exposures showing the actual relations were not observed. West of North Rocky Pass vitric tuff overlies fossiliferous mudstone.

In the southern portion of Willow Wash rare tuffaceous layers six to 12 inches thick contain abundant gastropod shells in a poor state of preservation. These have been identified by Dwight Taylor, of the U.S. Geological Survey, as representing *Valvata humeralis*, *Viviparus* cf. *V. Turneri Hannibal*, Hydrobiidae indeterminate and (?) *Promenatus kansasensis* (Baker). Also identified was a freshwater clam *Sphaerium* n. sp. Regarding the age of the assemblage, Taylor says (personal communication):

> The most precise age assignment warranted by the fossils is late early Pliocene to early middle Pliocene. *Valvata humeralis* and *Promenetus kansasensie* are not yet known from beds older than middle Pliocene; *Viviparus turneri* has not yet been found in beds younger than early Pliocene. The ranges of these species may well be extended by future collecting. The *Sphaerium* is closely related to a new species known from the middle Pliocene Teewinot formation in Star Valley, Idaho-Wyoming, and in Rockland Valley, south-central Idaho. It also shows resemblances to an undescribed species from the early Pliocene of Malheur County, Oregon. This evidence places the collection from the Grouse Creek Mountains with reasonable definitness in the early or middle Pliocene. Most probably the age is late early or early middle Pliocene, judged by the known ranges of the species and by their affinities.

Rhyolite member. Resting on the mudstone-vitric tuff member at the south end of the Grouse Creek Mountains are rhyolite flows which form isolated buttes. The rocks are reddish brown, contain abundant lithophysae and amygdaloidal cavities. In thin section they are composed of dusty glass in which a spherulitic arrangement of crystallites has developed. Phenocrysts in the glass are quartz, more rarely sanidine, and are generally about 2 mm in diameter. Flow banding is visible in the outcrops but is not prominent in thin section. The rhyolite member is 150 to 200 feet thick.

Lithic tuff-vitrophyr member. On the southwest side of the range, in part lying on the rhyolite member, is a poorly exposed sequence of lithic tuffs, felsites and vitrophyrs. They form gently rounded hills drained by relatively deep and widely spaced gullies. In different parts of the area they may assume different colors, red, white and black being the most common, but yellow and even green are occasionally observed. The lithic tuffs contain pebbles which can be recognized as representing the previously described formation from the Ordovician(?) quartzite to the red rhyolite, as well as rare pebbles of metamorphic rock (quartz schists containing amphihole and pyroxene) not observed to crop out in the area mapped. They include also pebbles of the plutonic rocks of the area.

The age of the lower part of the Salt Lake formation has been established as approximately late early or early middle Pliocene. The contained fauna is similar to that described by Mapel and Hail (1956) as occurring near the base of the Salt Lake formation in

Cassia County, Idaho. The units recognized by Mapel and Hail in the Salt Lake formation are similar to those in the southern Grouse Creek Mountains which are also assigned to that formation.

Unidentified Conglomerate

Overlapping older rocks on the south and west side of the range, and also cropping out on the north flank of Bovine Mountain, is a conglomerate mantle. It is characteristically furrowed by shallow, closely spaced gullies, in contrast to the lithic tuff-vitrophyr member of the Salt Lake formation. Most of the unit is composed of unconsolidated but well stratified conglomeratic material. The constituent pebbles and boulders are locally derived, including granite, diorite and sedimentary rocks. Within the unit are beds up to 20 feet thick of weakly consolidated conglomerate. At the south end of the range the unidentified conglomerate has a minimum thickness of 300 feet. It is not correlative with any other local unit known to the writer and possibly represents strictly local erosional debris shed by the Grouse Creek Mountains near the end of Pliocene time.

Quarternary System

The Quarternary deposits of the area are stream gravels, flood plain deposits, talus debris and lacustrian deposits. Stream deposits and alluvial fans are particularly well developed on the east side of the range, where talus slopes are also well displayed. Deposits left by Lake Bonneville in the form of beaches, terraces and bars are ubiquitous around the margins of the range.

PLUTONIC ROCKS

General Statement

The plutonic rocks of the southern Grouse Creek Mountains crop out along the northern flank of Bovine Mountain and make up the central portion of the range south of Rocky Pass. North of Rocky Pass they are exposed continuously to the east of the crest of the range for a distance of two miles. Isolated outcrops of granitic rock may be found north and east of Bovine Mountain where they protrude through the veneer of Cenozoic sediments. Isolated lamprophyr dikes occur in Bovine Mountain as much as two miles south of the principal outcrop of plutonic rock. The total area of exposure of plutonic rock is about 10-1/4 square miles. It is eight miles from the easternmost exposure of plutonic rock to the westernmost, and 4-1/4 miles from the northernmost to the southernmost. Although the writer believes there is only one pluton in the southern Grouse Creek Mountains, for the sake of convenience its parts will be referred to in the following discussion as (1) the Willow Wash massif, including that part which is principally in the drainage of Willow Wash in Sections 11 and 14, T. 9 N., R. 17 W; (2) the Rocky Pass massif, which crops out largely in the four sections which have a common corner at the northwest corner of Section 1, T. 9 N., R. 17 W.; (3) the Devils Playground massif, which occupies parts of Sections 4, 5, 6, 7, 8, and 9 of T. 9 N., R. 16 W.; and the Bovine mountain massif, which is exposed discontinuously in Sections 34 and 35 of T. 10 N., R. 16 W., and in the northeast quarter of T. 9 N., R. 16 W. Plate I shows that the Rocky Pass and Devil's Playground massifs are joined by a neck 1000 feet broad between exposures of Paleozoic rock. The neck joining the Willow Wash to the Rocky Pass massifs is obscured by stream gravels but petrographic continuity of the plutonic rock on both sides of the gravels shows the two massifs are continuous.

Within the pluton there are two major phases, a quartz monzonite which makes up 93% and a quartz diorite which makes up 7%. The quartz monzonite is divisible into a gray and a red phase and the quartz diorite is divisible into a non-chloritic and a chloritic phase. The relative proportions of the four phases are:

	Approximate Outcrop Area (Mi^2)	Per cent
1. Gray quartz monzonite	7-3/4	75
2. Red quartz monzonite	1-3/4	18
3. Quartz diorite	1/2	5
4. Chloritic quartz diorite	1/4	2

Gray Quartz Monzonite

Distribution

Gray quartz monzonite makes up all of the Devil's Playground massif, most of the Rocky Pass massif, the northeast third of the Willow Wash massif, and the northern part of the Bovine Mountain massif. It makes up 75% of the pluton as seen in plan view.

Description

Macroscopic features. The distinctive features of the gray quartz monzonite is a light gray color when seen *en masse*. In the hand specimen it is light gray and of granitic aspect. Quartz, feldspar and biotite can usually be recognized with the naked eye and the term leucogranite is often applicable as a field name although actually the rock is preponderantly quartz monzonite. The typical rock of the phase crops out at Rocky Pass and at Devil's Playground, a very conspicuous outcrop of quartz monzonite having an area of about one square mile centered at the S. W. corner of Section 4, T. 9 N., R. 16 W.

The rock is light gray, the color due to the blending of the white of feldspar and the black of biotite. The feldspar occurs as a background in which individual crystals cannot generally be recognized. Occasional cleavage surfaces 2 to 4 square mm in area reflect light with vitreous luster and rarely the reflecting surfaces have prismatic form. Colorless quartz in grains 3 to 10 mm in diameter appears to make up about 25% of the rock. Black to dark brown biotite with glistening vitreous luster in flakes one to 4 mm in diameter appears to make up 5% to 15% and is the only recognizable mafic mineral. The range in the apparent tenor of biotite is due to a slightly gneissic structure of the rock. Subhedral to anhedral feldspar phenocrysts 15 to 20 mm in length make up less than 2% of the rock. (See Table 1.)

Microscopic features. Quartz makes up an average of 34% of the rock, as determined by Rosiwal analysis of two representative thin sections. It is present in anhedral grains which range in length from one to 10 mm, with a large concentration in the 4 to 5 mm sizes. There is a pronounced tendency for several quartz grains to cluster together, making an aggregate 8 to 15 mm in diameter. Between quartz grains the boundaries are generally irregular and angular, although in any one aggregate it is possible to find boundaries between grains that are so irregular in detail that they are properly described as sutured and also to find boundaries that are straight for a distance of 0.1 mm or rounded on a similar scale. Between quartz and potash feldspar the boundaries are irregular to rounded but not sutured. Between quartz and plagioclase the boundaries are often determined by the crystal form of the feldspar and are therefore straight to irregular.

The larger quartz grains contain blobs of quartz which differ in optical orientation from the host. Angular grains 0.1 to 0.01 mm broad are concentrated near the margins of some quartz grains but are not conspicuous in the quartz as a whole. Feldspar inclusions are very rare. Biotite flakes 0.3 mm long are generally observed in the quartz aggregates but are usually found between quartz crystals, not within them. Apatite, epidote and magnetite inclusions in grains 0.08 mm broad have been observed. Minute inclusions, presumed to be liquid or gas-filled, are observed in every field of quartz under high magnification. Occasionally these are arranged in streaks or chains which extend across a quartz grain and whose orientations appear crystallographically controlled. To a greater or lesser degree all the quartz shows undulatory extinction, and in larger grains this type of extinction is pronounced.

Orthoclase and microcline together make up 39% of the rock, orthoclase constituting 24% and microcline 15% by Rosiwal's analysis. It is possible that in the analysis some of the microcline was measured as orthoclase since the characteristic microcline twinning used to distinguish the two minerals is occasionally indistinct. Both are perthitic, the orthoclase more so than the microcline. The habit of the two is similar. The potash feldspar occurs in anhedral grains ranging from 3 to 15 mm in length. Like the quartz, grains of the feldspar tend to occur in aggregates made up of grains in the larger sizes. The boundaries between grains of potash feldspar within the aggregates are irregular. Along 10% of the boundaries there is a highly irregular zone of albite(?) about 0.05 mm wide resembling a reaction rim which gives the boundaries a sutured appearance. The boundaries between potash feldspar and plagioclase are irregular to straight. Mineral inclusions in the potash feldspar are (1) albite as perthite which makes up between 0.1% and 2% of the grains, (2) biotite in flakes about 0.3 mm long making up less than 0.1%, (3) rare albite in slender laths about 0.05 mm long, and (4) occasional flakes of sericite. The extinction of the feldspar is generally uneven but is uniform in a small percentage of grains and is sometimes undulatory.

Plagioclase (An_{23}) makes up 20% of the rock. The range in composition of the zoned crystals is from An_{22} to An_{24}, determined optically by the universal stage technique. It forms subhedral crystals about 4 mm long distributed between the aggregates of quartz and potash feldspar. The boundaries between grains tend to be straight. Inclusions in the plagioclase, concentrated near the rims, are more abundant than in the quartz but still not common. The most abundant is quartz in rounded grains 0.8 to 0.2 mm in diameter which makes up less than 0.1% of the plagioclase crystals. Muscovite in irregular flakes up to 0.02 mm long, sericite, epidote in grains up to 0.1 mm broad, and sphene have been observed. Poorly developed zoning is characteristic of the plagioclase. Crystals which do not extinguish successively in concentric zones betray zonation by the concentric arrangement of clayey alteration products concentrated in zones. The rock contains very rare crystals of myrmekite 0.2 mm broad where quartz forms vermicules which are curved and bent and appear to show little relation to the crystallographic directions of the feldspar.

Biotite occurs in stubby flakes 0.25 to 2.5 mm long, the average being 1.5 mm, and makes up 7% of the rock. It is pleochroic with X = pale yellow-brown, Y and Z = dark greenish brown to opaque. Flakes seen normal to (001) have straight boundaries parallel to the cleavage and usually ragged terminations. Basal flakes are generally irregular, although some of the smaller flakes have poorly developed hexagonal outlines. Biotite typically occurs between crystals of quartz and feldspar. The larger flakes generally show irregular intergrowth either with a brownish-green chlorite developed near the edges of the biotite crystals or with a weakly pleochroic deep reddish-brown mica which occurs in patches in the flakes, giving them a mottled appearance. In large flakes seen normal to (001) the reddish-brown mica and chlorite interleave with the normal biotite. Inclusions in the biotite are apatite, plagioclase, epidote, and quartz. No pleochroic haloes were observed. There is a common association between biotite and epidote, the latter forming irregular grains generally about 0.2 mm in diameter at the borders of or between biotite flakes.

Epidote with birefringence between 0.02 and 0.04 occurs in irregular and embayed grains in association with the biotite, as inclusions in the plagioclase, and also disseminated along crystal boundaries in grains about 0.05 mm in diameter. Epidote makes up less than 1% of the rock. Other accessories observed are sphene, apatite, magnetite and chlorite, together making up a small percentage of the quartz monzonite.

The texture of the quartz monzonite is coarsely hypautomorphic-granular and slightly porphyritic (Fig. 2 and 3 (a)). Since the plagioclase grains show rather poorly developed crystal faces the texture of the rock is granitic more than monzonite (cf. Grout (1932), p. 84).

Quartz monzonite from Devil's Playgro
The field shows quartz (clear), plagioc
some zoned, perthitic orthoclase and t
crystals of microcline. The microcl
and a portion of the orthoclase in the lo
center shows an irregular rim of plagi
clase. Camera lucida drawing, times

Fig. 2

TABLE 1

Mode of the Gray Quartz Monzonite (226" P)

Mineral	Range (%)	Average
Quartz	10 - 40	34
Orthoclase (plus microcline)	10 - 65	39
Plagioclase (An_{20} to An_{32})	15 - 60	20
Biotite	5 - 20	7
Accessories, including weathering products (Epidote, sphene, apatite, magnetite sericite, chlorite, clay, calcite.)	Small	1

Variation

Within the pluton there is a small range in composition but a wide range in grains size. A large but unknown fraction of the pluton is represented by the rock which crops out in isolated exposures north of Bovine Mountain in Sections 1, 2, 3, 11 and 12, T. 9 N., R. 16 W. The texture is hypautomorphic- to allotriomorphic-granular but the average grains size is between 0. 5 and 1. 5 mm with occasional large crystals attaining 3 mm. Figure 3 illustrates the texture of the rock which forms the north part of the Bovine Mountain massif.

Fig. 3

Quartz monzonite from Section 1, T. 9 N., R. 16 W., showing the fine-grained texture typical of the rock in the northern portion of the Bovine Mountain massif. Camera lucida drawing, times 10.

Elsewhere, in the vicinity of Rocky Pass, North Rocky Pass and Devil's Playground, the range in texture is from rock in which phenocrysts make up 5% to that in which they are absent, or from relatively coarse rock such as that typical at Rocky Pass to medium-grained rock such as the north of Bovine Mountain. The distance over which such variation takes place is generally on the order of hundreds of feet. In traversing the pluton one notices a gradual decrease in phenocrysts and then their gradual reappearance, or a similar variation in grain size. Pronounced deviations from the typical plutonic rock, such as highly porphyritic facies, make up less than 10% of the quartz monzonite.

At Devil's Playground there are at least two areas measuring five or ten feet in diameter of medium-grained quartz monzonite which grades into the coarse-grained and typical plutonic rock over a distance of ten feet. The medium-grained rock is quartz monzonite in composition but has a curious texture which consists of a normal granitic texture upon which appears to be superimposed an aplitic texture: The normal granitic or monzonitic texture may be slightly porphyritic; largely between but also within the grains which have the normal textural relationships are patches, trains and isolated rounded grains of quartz 0.01 to 0.15 mm in diameter. The volume of the rock made up of the small and rounded quartz grains ranges from negligible to more than 25%. When the fine-grained material makes up a large fraction of the rock the quartz monzonite resembles one contaminated by aplitic material. When the fine-grained quartz makes up a small fraction of the rock the term "granitic intergranular" texture seems appropriate since it stresses the over-all granitic texture and calls attention to the location of the fine-grained quartz in the interstices between the grains of the granitic matrix. Figure 4 shows two views of this textural feature.

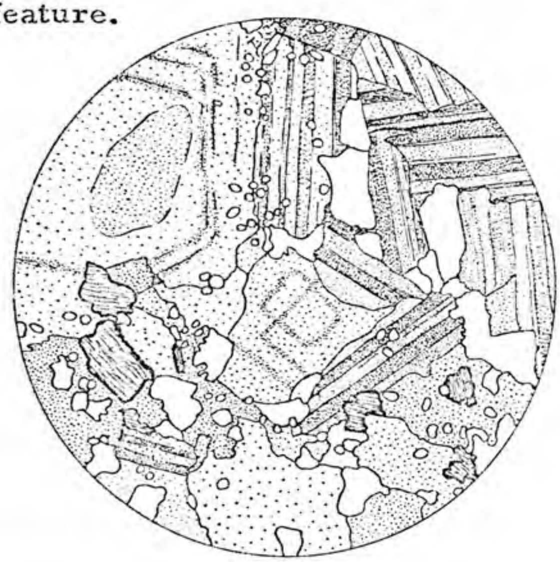

Fig. 4 (a)

Fig. 4 (b)

Quartz monzonite showing incipient granitic intergranular texture at Devil's Playground. Note that the fine-grained quartz forms principally between the larger grains but also occurs as rounded blebs within them, particularly near their borders. Camera lucida drawing, times 10.

Quartz monzonite showing extreme granitic integranular texture near border of pluton. Relatively few quartz blebs are included in the larger plagioclase crystals. Although this field shows mostly large-grained plagioclase, about 20% of the large grains in this rock are quartz. Camera lucida drawing times 10.

Schilieren have been observed in only two localities. One indefinite streak of mafic concentration was found near the border of the pluton on Citadel Peak, the highest peak of granitic rock. Microscopic examination showed it to be a granite whose texture has aplitic affinities in that it is composed of layers or bands 10 mm thick alternately of melaplite and melagranite, biotite being principal mafic mineral. The zone of streaking is 10 feet long, 2 feet wide. On the west side of Rocky Pass a single streak of biotite concentration was found which measures thirty feet long and two inches wide.

Very indefinite streaking or banding in the granitic rock can be seen at almost every outcrop. Close examination reveals that it is caused in part by a slightly gneissic fabric of about 50% of the plutonic rock. In many of the outcrops, however, it is caused by a differential concentration of lichens and seems more closely related to the prevailing wind and its eddies than to variations in the composition or fabric of the granite.

Inclusions

By the term "inclusion" is meant a marked and abrupt compositional or textural inhomogeneity whose form is rounded or which appears to be a remnant of sedimentary rock surrounded by plutonic rock. Markedly elongate inhomogeneities are termed "dikes" and are discussed in the succeeding section. Inclusions in the pluton are of three sorts, (1) basic inclusions, (2) pegmatite inclusions, and (3) sedimentary inclusions.

Basic inclusions. Throughout the quartz monzonite are rounded masses 2 to 12 inches in diameter of rock more basic than the surrounding pluton. In abundance they range from one such inclusion in every 20 square feet of outcrop surface to one in every 1000 square feet. They occur most abundantly within 2000 feet of the border of the pluton, and are particularly numerous in and near the contact of the quartz monzonite with the quartz diorite. They range in size from 1/2-inch in diameter to 18 inches, averaging between 2 and 3 inches. They may stand out boldly as dark patches on the light surface of the granitic rock or may even weather out in relief. More usually they are inconspicuous and are discovered by a careful examination of the surface of the outcrops. They occur rarely in association with fissures marked by iron staining of the granitic rock but are commonly isolated from other marked inhomogenieties of texture or composition. In texture they are granitic, granitic porphyritic, or dioritic porphyritic with the generally small but numerous mafic crystals distributed evenly through the groundmass and phenocrysts. In composition they are mafic grandodioritic or mafic dioritic. Plagioclase determined on the universal stage to be An_{52} has been found but more usually the composition of the plagioclase lies between An_{30} and An_{40}. Biotite, hornblende and magnetite are the common mafic minerals and rutile is a common accessory. Zonation of the larger inclusions can sometimes be seen in the field, with the rim more basic than the core. In an extreme form this zonation results in the complete disappearance of the basic core and a shell of dark diorite encloses granitic rock entirely similar to the country rock. No such zonation was detected on scale of a thin section.

Pegmatite inclusions. A second type of inclusions was found only on the west side of Rocky Pass. It consists of an apparently spherical mass of pegmatitic orthoclase surrounded by pegmatitic quartz. Two such bodies were found, one measuring 2-1/2 feet in diameter, the other 10 feet. The quartz border of the smaller is 4 inches thick, of the larger about one foot thick. No feeder dikes were found leading to thes e inclusions although the smaller is well situated for the exposure of such a dike if it existed.

Sedimentary inclusions. Inclusions of sedimentary rock are common within 100 feet of the margin of the pluton, rare in a zone 100 to 500 feet from the margin, and were not found deep within the pluton. The form of the inclusions is generally elongate parallel to the margin of the pluton and the size ranges from 2 by 5 feet to 15 by 50 feet. The larger inclusions appear to be most common within

50 feet of the margin of the quartz monzonite. The contact of the sedimentary inclusions with the plutonic rock was sharp in all observed exposures. About 60% of the inclusions are surrounded or partly surrounded by a border of aplitic rock up to 10 feet broad which is in sharp contact with the inclusion but in gradational contact with the surrounding granitic rock. Calcareous inclusions are generally recognizable only as a mass of actinolite, wollastonite, and diopside with minor calcite but in rare cases may be quite uneffected by contact metamorphism. The quartzite inclusions are often relatively high in biotite but may appear to lack alteration. About 200 feet north of the southern boundary of Section 6, T. 9 N., R. 16 W., there is a mass 25 feet long and six feet wide of garnet-epidote rock which dips steeply south. This was the only tactite body found although a search was made for others.

Dikes

Aplites. Aplite dikes occur most abundantly within 2000 feet of the border of the pluton but are also found deep within it. Because aplite dikes tend to occur in clusters or swarms it is difficult to state their abundance exactly, but as a measure it can be said that an aplite dike can be found in any area of 100 by 100 feet within 200 feet of the margin of the pluton. Deep within the pluton, such as in Section 3, T. 9 N., R. 16 W., aplite dikes occur within every area of 1000 by 1000 feet. At Rocky Pass and Devil's playground it is most usual to see groups of two, three or four aplite dikes of similar attitude separated by three to ten feet. Such a group is separated by 50 to 100 feet from the nearest similar group.

The average width of the aplite dikes is two inches, the range from 1/2-inch to four feet. Rarely they bulge out into irregular masses ten feet wide. No difference, neither in hand specimen nor under the microscope, is recognizable between the aplite of the dikes proper and of the aplite masses. The dikes cannot usually be traced for more than 200 feet along their strike. Those which can be followed continuously for more than 100 feet are rare. Undoubtedly this is partly due to the discontinuity of exposures, but no aplite was found which when projected along its strike from one exposure to the next was traceable for more than 200 feet. The borders of the aplite dikes were observed to be sharp in all cases.

Most of the aplities, as seen under the microscope, have a slightly prophyritic texture with occasional grains of feldspar two mm long present although the large majority of the grains of the rock are less than one mm long. The mode of one aplite determined by Rosiwal analysis was:

Quartz	46
Orthoclase	30
Microcline	4
Plagioclase (An_{15}?)	18
Biotite	2

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One or two percent of the aplite dikes, particularly those over six inches in width have irregularly shaped cores of pegmatitic quartz and orthoclase in crystals up to three inches long. The cores rarely make up more than 10% of the dike by volume. It was observed that whereas most aplite dikes appear homogenous (except for their cores), two were encountered displaying a recognizable structure. One of these resembled the structure of slates or shingles on a roof. Plates three inches thick, six inches borad and elongate in the direction of strike of the dike were stacked in echelon in a vertical direction to make up the dike. The other structure was similar except that no distinct plates were visible; rather veinlets of hematite staining divided the dike horizontally. It was possible to make a cross-section of the dike for microscopic study, which showed that the veinlets of staining were concave in the same direction as they crossed the dike, stacked like tea cups on a shelf and separated one from the other by about 10 mm. The microscopic preparation also showed that the dike had an aplitic texture dominated by plumose mymekite, a textural feature which is quite common but not typical of the aplites of the pluton. Grains of garnet about one mm in diameter and usually deeply embayed were found in about one-third of the aplites studied microscopically but probably occur in only about 5% of the dikes as a whole.

Pegmatites. One pegmatite dike three feet thick and traceable for 40 feet was found west of Rocky Pass. The dike is composed of quartz, 40%, orthoclase, 40% plagioclase (An_{10}), 18% and biotite less than 2%. The average grain size is greater than 20 mm. The biotite is in books 10 x 10 mm in dimension which are arranged within the rock in such a way that it has a graphic aspect. The dike has a micropegmatitic fabric and is not zoned.

Contacts

The contact of the quartz monzonite with the quartz diorite is described with the quartz diorite. Its border with the sedimentary rocks often shows the development of characteristic mineral assemblages, textures and structures.

Compsotional variations. In the pluton and within 20 or exceptionally 50 feet of the contact with the wall-rock are found the principal compositional variants of the quartz monzonite phase. The rock rarely takes on a melanocratic aspect with an increase in the amount of biotite and also in the anorthite content of the plagioclase, the appearance of hornblende and a decrease in the potash feldspar. This is particularly the case on the northwest side of Citadel peak, in Section 3, T. 9 N., R. 17 W., where within ten feet of the contact the rock is locally a quartz diorite. In general, however, the contact rock has the composition of a granite, quartz monzonite or granodiorite in which there is no increase perceptible to the naked eye in the content of mafic minerals. On the south and east side of Citadel Peak the contack rock appears to be a leucogranite. Microscopic examination of miscellaneous samples in this locality shows that here there is a range in composition from granite to granodiorite. This seems to be typically the case also in the other areas where the contact is exposed. There appears to be no correlation between the lithology of the sedimentary contact rock and the composition of the adjacent plutonic rock.

Three minerals, chlorite rutile, and epiodite are characteristic of the border facies of pluton regardless of whether the rock representing it is granite, quartz monzonite or granodiorite. If the basic inclusions are considered a contact facies of the pluton then the generalization can be made that the occurence of these minerals is restricted to the contact with very minor exceptions. They are often associated together and the association chlorite-rutile is particularly characteristic. Most of the contact rocks of the pluton, however, are without a distinctive mineral assemblage. Hematite and limonite are generally present in the contact rocks and by their reddish color emphasize the position of the border of the pluton. Thin section study shows the iron to be in the form of coatings on grain boundaries and on the borders and cracks in the mineral grains.

<u>Textural variations</u>. It is in its texture that the plutonic rock near the contact is most distinctive and variable. Micropegmatite and myrmekite are typical textures near the border, but aplitic and porphyritic and granitic intergranular facies are also found. Textural varieties do not generally persist along the strike of the contact for more than 1000 feet and more generally the change which can be seen with the naked eye is on the order of feet or tens of feet. These textural peculiarities associated with the border do not usually persist into the pluton for more than 20 feet.

It is mentioned in connection with the sedimentary inclusions that the contact of the pluton with sedimentary inclusions is often through a zone of variable width of fine-grained rock. The converse of this is also true. In the S. W. 1/4 of Section 3, T. 9 N., R. 17 E., there are at least two apophyses of the pluton in the sedimentary rock (only the larger is shown on Plate I). The smaller of the two measures 8 x 15 feet and grades from its center from medium-grained quartz monzonite into fine grained porphyritic quartz monzonite with definite granitic intergranular texture near the edge. The whole apophysis is surrounded by biotite-bearing Eureka(?) quartzite with which it is in sharp contact. The borders of the larger apophysis happen to be poorly exposed, but where the contacts are visible they also are composed of more fine-grained rock than the central portion.

At the Compressor mine the plutonic rock is also fine-grained near the contact. It is composed of anhedral orthoclase, microcline, plagioclase and quartz in serial-sized grains 0. 5 to 0. 05 mm in diameter. Biotite flakes up to five mm in diameter have a subparallel orientation in the rock which is sufficiently pronounced to give it a slightly schistose appearance. Under the microscope the texture of the quartz and feldspar matrix is granitic, but disseminated without preferred orientation in the matrix is myrmekitic feldspar which is present in highly irregular to almost rectangular patches about 1. 5 mm in width. They constitute about 20% of the rock. The myrmekite of the patches of more regular shape has such regular structure that crystallographic control of the quartz blebs by the feldspar is obvious. That in irregular patches is poorly developed, consisting of blebs of quartz averaging 0. 04 mm in diameter in a matrix of larger but optically discontinuous feldspar, both potash and soda-lime. The myrmekitic character of these patches is betrayed only by the optical continuity of some of the neighboring quartz blebs. A radial structure can be detected in some of the irregular patches of mymekite which is unconnected with but emphasized by the arrangement of the subordinate mafic minerals. One example of an atypical myrmekititic structure was found which consisted of an almost square section of a crystal of oligoclase measuring one mm on a side and containing several small blebs of quartz. Surrounding the oligoclase crystal is a border one mm thick of very poorly developed mymekite which has a pronounced radial structure in the aggregate and in which small (0. 3 mm) flakes of biotite participate. The oligoclase crystal is impregnated with hematite which is so heavily concentrated along the cleavage planes of the feldspar that the oligoclase is almost opaque. However, surrounding the crystal, forming a barrier between it and the surrounding mymekite, is a zone of oligoclase about 0. 02 mm thick which is in optical continuity with the main part of the crystal and which is free of hematite. Brown biotite in books whose dimensions are about 0. 9 by 0. 03 mm in cross-section are distributed with only the slightest suggestion of lineation to make up about 5% of the rock. The biotite grains are conspicuously smaller (0. 3 mm long) and more sparsely disseminated in the patches of myrmekite. Chlorite and garnet are the only accessories. Limonite staining is sparce but pervasive.

Fine-grained contact facies of the quartz monzonite are also found on the north flank of Bovine Mountain is Sections 7, 8, and 9, T. 9 N., R. 16 W. In some places the rock appears aplitic, in other places it resembles fine-grained granite. In all localities where the relations were clearly exposed the fine-grained rock grades into the plutonic rock of normal texture. Along the eastern boundary of

Section 1, T. 9 N., R. 17 W., where the pluton is in contact with quartzite of the Chainman formation, the contact rock resembles quartz porphyry; the relations are not well enough exposed to determine whether the prophyry grades into normal plutonic rock or whether it forms a distinct dike.

Medium-grained quartz monzonite, granite or granodiorite also forms the contact of the pluton with the sedimentary rocks. On the north flank of Bovine Mountain localities in which fine-grained rocks form the contact are separated by localities in which the contact is formed by medium-grained rock. Medium-grained rock also forms much of the contact to the east of the Compressor mine and on the west wall of Emigrant Wash.

Very coarse-grained and porphyritic quartz monzonite forms the contact rock in Sections 25 and 36, T. 10 N., R. 17 W. Here the average grain size of the pluton is between five and 10 mm and euhedral orthoclase phenocrysts attain 35 mm in length. The coarse-grained plutonic rock extends from the abrupt contact 1000 or more feet into the pluton. Along this contact, and particularly along the contact south of the road leading to North Rocky Pass, the coarsest facies of plutonic rock was found. The granitic dikes which occur in the sedimentary rock in this vicinity (and which are shown on Plate I) have medium-grained textures.

Pegmatitic contact rock occurs in the northwest corner of Section 11, T. 9 N., R. 17 W. Traversing from the quartz diorite northwestward toward the sedimentary rock one encounters a zone about 150 feet wide in which the concentration of mafic minerals becomes progressively attenuated. Fifty feet from the contact the rock is apparently normal quartz monzonite. Twenty-five feet from the contact the rock is coarse-grained and the biotite in it is in thin books about 10 mm in diameter which are arranged to give a graphic aspect to the rock. At the contact the rock is pegmatite similar to that found in the form of a vein on the west side of Rocky Pass.

Gradational contacts. In contrast to the chloritic quartz diorite, the quartz monzonite exhibits gradational contacts only locally and on a small on the east side of Citadel Peak. Here at several localities the contact is indistinct for a distance of 5 to 25 feet along its strike and the indeterminate zone is one or two feet wide. On the east side of Citadel Peak the sedimentary contact rock is Eureka(?) quartzite and most of the contact is sharp.

Faulted contacts. Faulted contacts are not difficult to identify but are more indeterminate than gradational ones. The fault zone is usually at least five feet wide. In such zones boulders or horses of sedimentary and plutonic rocks occur together in a chaotic structure in a matrix of soft material which weathers in such a way as to obscure the relations. To make precise location of the contact along faults even more difficult, the faults are often *en echelon* and a fault zone 10 to 30 feet wide may be seen. A good example of a faulted contact is located 650 feet east and 1300 feet north of the S. W. corner of Section 12, T. 9 N., R. 17 W. where the Simonson formation is in contact with a microcline granite facies of the quartz monzonite.

Sharp contacts. Where the relations may be most clearly seen sharp contacts are by far the most usual. In such localities a hand or even a finger may cover the contact. Between the sediment and the plutonic rock is usually a zone of weathering products resembling clay or gouge which makes recovery of samples of the contact for microscopic study difficult. Rarely the plutonic rock and the sediment are fresh and hard, and in such cases microscopic study shows the contact to be sharp on a microscopic scale. Citadel Peak has already been mentioned as the locality where gradational contacts may be observed; it is also a conveniently accessible locality where there are well exposed sharp contacts.

Interbedded contacts. The term "interbedded contact" is used to designate those in which the sedimentary and plutonic rocks are interbedded in a manner similar to the interbedding of the limestone and quartzite of the Stratearn(?) formation. On the east side of the pluton, between Rocky and North Rocky Passes, the granitic rock is interbedded with limestone. The beds of granitic rock occur as lenses up to 18 inches thick and 30 feet long along the bedding planes of the limestone. They are separated from one another by an average stratigraphic distance of 15 feet and occur as much as 150 feet from the border of the granitic mass. On the extreme east side of the pluton, in the N. W. corner of Section 24, T. 9 N., R. 16 W., an outcrop of the Pre-Cambrian phyllite formation shows similar interbedding with the pluton. At both localities where interbedding occurs the sedimentary rock involved is a carbonate; at Rocky Pass it is limestone and in Section 24 it is dolomite.

Red Quartz Monzonite

Distribution

The red quartz monzonite makes up the southern portion of the Bovine Mountain massif, where it occurs in two large exposures in Sections 3, 10, 11, 13, 14, 15 and 22, T. 9 N., R. 16 W. Here the total area of outcrop is about 1-1/2 square miles. It also occurs bordering the Rocky Pass massif in two areas, one near the N. W. corner of Section 36, and the other near the S. W. corner of Section 35, T. 10 N., R. 17 W. Each exposure in the Rocky Pass massif has an area of about 100 acres. It also occurs as two dikes no more than 10 feet broad and traceable for about 100 feet located approximately in the center of the quartz monzonite phase of the Willow Wash massif.

Description

The rocks mapped as red quartz monzonite are distinctly granitic in texture and distinguished by a reddish color which makes them distinctive in the field. Where they are colored most intensely red they are traversed by numerous closely spaced veins of hematite one to six inches wide. The veins may be so closely spaced as to cause the staining to coalesce, forming a rock banded in shades of rust-red. More usually the veins are separated by two to 20 inches of gray quartz monzonite which is similar to the rock of the gray quartz monzonite phase of the pluton. Individual veins can be traced five to 15 feet before they terminate by pinching out or join with another vein. They are most closely spaced near the center of Section 15, T. 9 N., R. 16 W. Radially from this locality they diminish in intensity of coloration and areal frequency. Since a detailed description of the red quartz monzonite would repeat much of what has been said of the gray it is sufficient to contrast the two phases.

Megascopic features. Veins of hematite staining make the red quartz monzonite distinctive. They are two to six inches wide and rust-red or brown at their centers. The typical vein has a central core of reddish-brown, dense, fine-grained rock 1/2-inch to four inches wide.

In the core individual mineral grains can usually be distinguished, although aphanitic cores have been observed. In some veins the central core is itself banded in shades of brownish-black to reddish-brown parallel to the length of the vein. Outward from the core there is a rusty halo in which there is a gradual decrease in the saturation of the brown hue over a distance of an inch, more or less. There is, however, a distinct hiatus between the grain size of the core and that of the surrounding plutonic rock.

Veins of iron staining are also seen which lack the central core. Some veins are more trails or wisps of rust in the plutonic rock. In areas as large as several acres veins are lacking but the rock nonetheless has a pink aspect.

Microscopic features. Microscopic study shows that there are certain characteristic differences between the red and the gray quartz monzonites. The differences are not pronounced in a comparison of one specimen from each phase but are evident if several representatives of one are compared with several of the other. Deferring description of the iron veins to the succeeding paragraph, the red quartz monzonite differs from the gray in the following respects:

(1) Many of the quartz and feldspar grains of the red quartz monzonite are cracked and shattered, and in the cracks there is a thin layer of hematite.

(2) Plagioclase crystals show more pronounced zonation in the red quartz monzonite. The zonation is accentuated by disseminated dusty hematite which occupies the centers of plagioclase crystals or which forms dusty zones surrounding the centers.

(3) Oligoclase exceeds orthoclase in the red quartz monzonite, the reverse is true in the gray.

(4) Microcline is rare to absent in the red quartz monzonite.

(5) The larger quartz grains in the red quartz monzonite are generally distinctly biaxial although they show oscillatory extinction to a lesser extent than those in the gray.

(6) Magnetite and sphene are important accessories in the red quartz monzonite, unimportant in the gray.

TABLE 2

Mode of the Red Quartz Monzonite (227" P)

Mineral	Range (%)	Average
Quartz	20 - 35	31
Plagioclase (An_{20} to 32)	25 - 40	34
Orthoclase	15 - 40	26
Biotite	6 - 10	8
Accessories (including weathering products)	Small	1

Veins

The iron veins are actually quartz-hematite-muscovite veins. Quartz is the principal mineral of the veins, making up more than 90% by volume. It occurs in anhedral, angular grains which range in size from 0. 01 to 1. 5 mm. In the typical vein, bands 3 mm wide parallel to the vein of quartz grains averaging 0. 2 mm alternate with bands of grains averaging 0. 06 mm in diameter. The bands interpenetrate so there is no sharp boundary between them. Minor orthoclase in the bands of larger quartz is distinguished readily from the quartz by its extreme turbidity, due to finely divided clay and hematite particles which it contains.

The iron minerals in the veins are pyrite, hematite and limonite. In the bands of larger quartz are founded pyrite grains 0. 4 mm in diameter and arranged in elongate clusters of five or six grains parallel to the length of the vein. Each pyrite cyrstal is surrounded by a zone 0. 03 mm broad of dark brown limonite which in turn is surrounded by a lighter rust-red zone of hematite. Radially outward from the pyrite-hematite-limonite clusters, in the cracks and intergrain boundaries of the nearby quartz, are veinlets of hematite which become less conspicuous centrifugally and at 3 mm from the cluster blend with the general and pervasive hematite staining of the vein. The pervasive hematite staining consists of films around the quartz grains making up the vein. The intergranular staining is particularly heavy in the bands of smaller quartz and gives them, under low magnification, a dusty and transluscent appearance in transmitted light and a mottled salmon-pink to rusty and cloudy appearance in reflected light. Magnetite occurs in accessory amounts in the quartz monzonite adjacent to the veins but is almost absent within them.

Muscovite makes up less than 1% of the vein matter. It is disseminated in or next to the bands of smaller quartz in ragged flakes averaging 0.1 mm long. The muscovite flakes are irregular in shape, show mottled extinction and are in many cases slightly bent. Patches of hematite in the veins are suggestive of the abundant former presence of biotite, but flakes indentifiable as biotite are very rare. Fig. 5 shows a typical microfield.

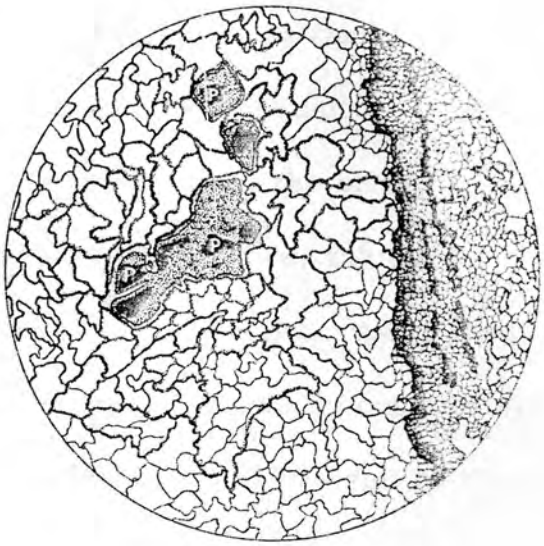


Fig. 5

Quartz-pyrite vein showing the pyrite (P in diagram) rimmed by limonite which is in turn rimmed by hematite. Hematite staining between quartz grains is represented by heavy, dotted lines and by the shading in the veinlet of fine-grained quartz on the right. Camera lucida drawing, times 10.

The contacts between the veins and the quartz monzonite are typically abrupt. There is a distinct hiatus in grain size between the veins and the quartz monzonite but a minor decrease in the amount of iron staining. Intergrain veinlets of hematite extend from the vein into the quartz monzonite and penetrate the larger crystals. Plagioclase within 30 mm of the vein is particularly deeply stained by the hematite, and the staining is usually most intense in the centers of the feldspar crystals, making them almost opaque. Away from the vein the staining diminished in intensity until about 30 mm from the veins staining is inconspicuous to absent. Less than half the veins have gradational contacts with the quartz monzonite. In such contacts vein quartz fills the interstices between the orthoclase and plagioclase phenocrysts of the quartz monzonite, taking the place of the normal quartz and plagioclase groundmass. Away from the vein the usual quartz background reappears gradually until at 30 or 40 mm from the vein the background appears uneffected by the introduction of vein matter.

Those hematite veins which appear to be merely zones of staining in the country rock are similar to the staining of the quartz monzonite adjacent to the quartz veins. Hematite films occupy the interstices between the grains of normal quartz monzonite and the plagioclase crystals have deeply stained cores. To a lesser degree this is also the case in that rock mapped as red quartz monzonite which has a pink aspect but is without veins.

Inclusions

Inclusions are considerably less abundant in the red quartz monzonite than in the gray. No sedimentary inclusions were found, no pegmatitic inclusions were found, and basic inclusions are inconspicuous and rare. Basic inclusions are found less frequently than one inclusion per 10,000 square feet of outcrop surface and those which can be found are indistinct. This relative paucity of inclusions appears to unrelated to the iron veins since inclusions are rare even where the veins are inconspicuous.

Dikes

Neither pegmatite nor basic dikes were observed in the red quartz monzonite. The aplite dikes are similar to those described with the gray quartz monzonite except that they are nowhere as abundant as they are at Rocky Pass or Devil's Playground and they may be stained by intergranular hematite.

Contacts

The contact between the red quartz monzonite and the sedimentary rock is poorly exposed except in Section 22, T. 9 N., R. 16 W.

Here the contact with the Precambrian formation is sharp. Elsewhere the structure of the contact is obscured by eluvium or alluvium. The outcrop already referred to in the N. W. corner of Section 24, T. 9 N., R. 16 W., may be close to the contact, in which case that contact is interbedded. The contact which almost parallels the western boundary of Section 15, T. 9 N., R. 16 W., locally shows silication of the sedimentary rock but along most of its length is poorly exposed.

Quartz Diorite

Distribution

Quartz diorite crops out only in the Willow Wash massif. In the drainage of Willow Wash it forms an outcrop pattern which is roughly rectangular with a length of 5000 feet a maximum width of more than 2000 feet. On the western wall of Emigrant Wash, in Section 14, T. 9 N., R. 7 W., it forms a tongue or strip 2000 feet long and 700 feet wide.

Description

The quartz diorite is characterized in the field by a light to dark olive drab color which always has an overtone of gray. Except in the vicinity of its contacts with surrounding rocks it is uniformly medium gray-green when seen en masse. In the hand specimen it is medium-grained and may or may not be porphyritic. Dark, rounded inhomogneities in color and texture, often misnamed "xenoliths" or even "cognate xenoliths," are common. It weathers to rounded outcrops and in places dark brown desert varnish forms on boulders of the quartz diorite.

Macroscopic features. The rock is massive and light drab gray-green. The over-all color is due to a light gray background in which individual mineral grains cannot generally be distinguished but in which one can sometimes see the reflection of light from cleavage surfaces measuring less than one square mm. In this matrix are dark green specks and irregular areas up to one mm broad of hornblende. Black biotite flakes ranging in bredth from the smallest visible to 5 mm are disseminated without orientation. Phenocrysts of light gray, earthy feldspar, separated from each other by 50 to 100 mm, make up one per cent of the rock. They are subhedral to anhedral, 5 to 10 mm in length, and are very rarely surrounded by a halo 0.5 mm wide of a dark green chlorite. Joint surfaces show a thin deposit of hematite.

Microscopic features. Plagioclase (An_{30}) makes up 65% of the rock. The oligoclase is in subhedral to anhedral crystals ranging serially from 0.2 to 1.0 mm long. The borders of the smaller crystals are generally straight whereas the larger crystals show poorly developed crystal form and have serrated or gently embayed borders. The smaller crystals are generally free of zoning, the larger ones are usually zoned. In one prominently zoned crystal the range in composition was from An_{22} (edge) to An_{38} (core); more usual is from An_{23} or 24 (edge) to An_{28} to 32 (core), with indistinct borders between zones. Oscillatory zoning was not observed. Inclusions of feldspar, quartz and mafic minerals are less common in the smaller than in the larger oligoclase crystals.

Microcline makes up around one per cent of the rock. It forms very irregular crystals up to three mm broad. Plagioclase laths ranging from 0.4 to 0.6 mm long are included in the microcline without preferred orientation and may project from the microcline into the surrounding matrix of plagioclase. The form and distribution of mafic minerals appears uneffected by the presence of microcline: they are included in the microcline in the same concentration that they appear in the plagioclase matrix.

Quartz makes up between 10% and 25% of the rock. Like the microcline it forms very irregular crystals 0.5 to 5.0 mm broad containing plagioclase laths and mafic minerals, but unlike the microcline it also forms grains about 0.2 mm in diameter which fill the interstices between plagioclase crystals.

Biotite is the principal dark constituent, making up 5% to 15% of the rock. It is in stubby laths or irregular flakes usually not more than 0.2 mm long but occasionally attaining five mm in diameter. The terminations of the laths are generally rough or jagged but not ragged. Parallel to the cleavage of the biotite laths the edges are straight. The borders of the flakes are rounded. Pleochroism is from light brown to dark olive drab. About 5% of the biotite is intergrown with light green chlorite of very low and slightly anomalous birefringence. The biotite is disseminated uniformly between feldspar crystals. It does not form abundantly as an inclusion within them.

Hornblende is generally subordinate to biotite but makes up 5% to 10% of the rock. It is in laths and grains not longer than 0.7 mm and usually 0.1 to 0.2 mm long. Prism outlines are well-developed but the laths are irregularly terminated. Cross-sections of the hornblende generally show well-developed (110) faces but poorly developed (100) and (010) facies. Pleochroism is from light to dark green. The distribution of the hornblende is similar to that of the biotite and there is a weak but perceptible tendency for the two mafic minerals to be associated in parallel growth.

Epidote, dominantly with the optical properties of pistacite, is a major accessory which makes up 0.5% to 5.0% of the rock. It is in highly irregular and sometimes deeply embayed crystals 0.01 to 0.5 mm broad which are usually associated with biotite and with biotite intergrown with chlorite.

Rutile is a common accessory which rarely makes up more than 1% of the rock. Like the epidote, it is in irregular and embayed crystals but is usually not more than 0.2 mm broad. It shows no tendency to be associated with any particular mineral.

Apatite is a very wide-spread accessory which typically occurs disseminated in needles 0.06 by 0.005 mm included in the plagioclase. Magnetite grains occur in very minor amounts.

Large phenocrysts in the quartz diorite are plagioclase having the same anorthite content as the matrix plagioclase. The phenocrysts are usually composed of two or more plagioclase crystals 2 to 3 mm long joined along irregular surfaces. The crystals can be seen to interpenetrate, with inclusions of one crystal in the other along their common border. The plagioclase crystals are composed of a mosaic of blocks of slightly differing optical orientation so that except in positions of uniform illumination on the microscope stage the phenocryst looks strongly mottled. Rounded blebs of quartz included in the plagioclase emphasize the mottling. The borders of the phenocryst are those of the constituent crystals, and these are serrated and/or gently embayed.

Due to the aggregate structure of the phenocrysts they contain deep embayments bordering crystals which project into the matrix.

The texture of the quartz diorite is medium-grained hypallotriomorphic and slightly porphyritic. Under crossed nicols the subhedral laths of plagioclase which make up a coarsely felty matrix dominate the texture. By means of an accessory plate it is seen that 1% to 5% of the feldspar has definite preferred orientation, but schistosity is not otherwise generally evident.

Fig. 6

Quartz diorite showing the typical felt-like texture dominated by subhedral plagioclase and the large grains of quartz forming a background in which plagioclase crystals are included. Camera lucida drawing, times 10.

The texture of the phenocrysts, which contrasts strongly with that of the matrix, is described above.

TABLE 3

Mode of Quartz Diorite (228" P)

	Range (%)	Average
Plagioclase (An_{24} to 32)	55 - 70	65
Microcline	0 - 5	1
Quartz	10 - 25	19
Biotite	5 - 15	8
Hornblende	5 - 10	4
Epidote	0.5 - 5	2
Rutile	0.1 - 1	0.5
Other accessories, including weathering products (magnetite, sericite, limonite calcite and clay)		0.5

Variation

Compositional variation is limited to a range in the amounts of biotite or hornblende which together make up 10% to 25% of the quartz diorite. The composition of the plagioclase has been observed to range between An_{22} and An_{41}, although in a single specimen the range is not as great. Near the contact with chloritic quartz diorite or quartz monzonite the quartz diorite may contain 15% to 20% orthoclase or microcline which occurs interstitially between plagioclase grains. Textural variations are very small. Completely nonporphorytic varieties may be observed but are rare. The grain size may be slightly larger or smaller than that described. However, the designation of the rocks as hypautomorphic and coarsely felty has not been observed to be incorrect.

Inclusions

Cognate inclusions. Darker inclusions in the quartz diorite are everywhere present. Generally they are about 6 inches in diameter and contrast faintly with the normal rock. In some areas apparently erratically distributed near the contact of the quartz diorite and the quartz monzonite, the inclusions are so abundant that they may make up 30% of the area of an outcrop of 100 square feet. Two varieties of inclusions can be distinguished, a porphyroblastic and a non-porphyroblastic variety, which occur in the ratio of 1:4. The inclusions range in size from 1/2-inch to 12 inches, 4 inches being average. It can be said quite generally that the inclusions differ from the surrounding quartz diorite in three ways, viz., (1) their grain size is smaller, (2) the concentration of mafic minerals is greater and (3) the plagioclase of the inclusions is sometimes very slightly (2 to 3% An) more basic than in the matrix. No mineral which is not present in the matrix will be found in the inclusion, and rare minerals in the matrix (such as rutile) will also be found in the inclusions.

Sedimentary inclusions. Two light gray inclusions of sedimentary rock are found in the quartz diorite. One, 8 x 20 feet in size, is composed of quartzite exposed on the eastern wall of Willow Wash and the other, 5 x 10 feet is of dolomite in Emigrant Wash. The quartzite inclusion is entirely surrounded by a zone one to 3 feet wide of chloritic quartz diorite with which it is in sharp contact. The dolomite inclusion is partially surrounded by a similar zone. At both inclusions the contact between the chloritic diorite and the quartz diorite is gradational, the contact between the sedimentary rock and the plutonic rock is sharp.

Dikes

Veins and dikes are absent within the area of outcrop of quartz diorite except near its borders. Two basic dikes were found 500 feet north-east of the Magnitude mine, and aplite dikes are common in the transition zone between the quartz diorite and quartz monzonite. The basic dikes are two and three feet broad, can be traced for approximately 15 feet along strike, and are composed of quartz diorite in which the mafic minerals equal the felsic in abundance.

Contacts

The contact of the quartz diorite with the sedimentary rocks is difficult to observe due to the cover of plants and eluvium. The one outcrop where the contact is well exposed is at the dolomite inclusion on the west wall of Emigrant Wash. Here the contact is sharp. Elsewhere good exposures show either a zone several feet wide of transitional chloritic quartz diorite between the quartz diorite and the sedimentary rocks, or else a zone of quartz monzonite 50 to 100 feet wide. In crossing the contact there may be local reversals in rock type, but generally the sequence is progressively from quartz diorite to quartz monzonite. As one crosses the zone of transition from the quartz diorite to the quartz monzonite the plutonic rock becomes lighter in color, dark inclusions become more noticeable and abundant but their average size decreases from 6 inches to two inches, phenocrysts become more abundant and the grain size of the rock increases. Texturally the zone of transition is marked by the disappearance of the hypautomorphic coarsely felt-like diorite texture and the appearance of the hypautomorphic porphyritic granitic texture. Concommitantly the quartz of the quartz diorite becomes more noticeable as distinct grains about two mm in diameter which do not include laths of plagioclase or grains of the mafic minerals. Phenocrysts of perthitic orthoclase appear and the anorthite content of the matrix plagioclase decreases from An_{30} to An_{25}.

Approaching the quartz monzonite contact from the quartz diorite the number of inclusions in the rock increases to a maximum 1% to 5% by volume and then abruptly decreases in the normal quartz monzonite. In the area of maximum inclusions aplite dikes appear. The inclusions, however, where their number is greatest, can be seen to have three aspects. (1) They appear as small (2-inch) homogenous inclusions of dark color. (2) They appear as larger (6-inch) inclusions in which the concentration of mafic minerals is relatively attenuated, and are therefore light in color. (3) They appear as medium dark inclusions (6 to 12 inches in diameter) with dark rims or as medium dark rims only, the rock inside the rim having the composition of the enclosing rock. There are all intermediate types between these three extreme aspects.

Chloritic Quartz Diorite

Distribution

The rocks mapped as chloritic quartz diorite are found along the borders of the quartz diorite in the Willow Wash massif. They are restricted to a belt generally no wider than 500 feet contiguous with the sedimentary rocks. In the vicinity of the Magnitude mine the belt of rocks of this phase widens to as much as 1000 feet, and locally it thins to several feet in width and even pinches out completely so that plutonic rocks of other phases are in contact with the sediments. Chloritic quartz diorite is also found bordering sedimentary inclusions in the area in which quartz diorite is dominant. The chloritic quartz diorite forms subdued and inconspicuous outcrops, weathering readily to a mantle of eluvium.

Description

Macroscopic features. The rocks of the chloritic quartz diorite phase are greenish and generally mottled in shades of green and white. The color is in places drab but does not have the gray aspect which is often a feature of the normal quartz diorite. The rocks are usually massive on the scale of a hand specimen, although occasionally moderately schistose representatives are found. Both in hand specimen and in thin section they show affinities with quartz diorite, but they are not usual members of that clan. The characterizing mineral of the phase in chlorite having the optical properties of pennine. Epidote is in many places as abundant as chlorite, hornblende is abundant and muscovite is conspicuous in some rocks mapped as chloritic quartz diorite. The grain size of the rocks is generally larger than in the normal quartz diorite and the texture appears in the hand specimen to be coarser than that of the quartz diorite and is granitic rather than dioritic.

The typical rock of phase is light olive-green seen from a distance. This peculiar color is caused by to white, earthy feldspar in which is disseminated dark olive-green epidote and amphibole and brownish-green chlorite. The feldspar forms in crystals about one mm long and also occurs in larger crystals ranging serially in length from one to 10 mm. Twinning striae can be seen on the cleavage planes of some of the larger feldspar crystals, which show very poorly developed crystal outlines. Quartz anhedra ranging in length from two to 10 mm are sometimes present but inconspicuous. The epidote and amphibole are in laths, blobs and irregular patches one to 5 mm in dimension and are difficult to distinguish from each other. The chlorite is in irregular flakes one to four mm long showing well-developed basal cleavage. The rocks as a whole gives the impression of being a homogenous mixture of the constituent minerals and lack planar or linear structure.

Microscopic features. Under the microscope plagioclase is observed to make up 60% of the rock (see Table 4). It is present in subhedral, interlocking crystals composed of high-soda andisine (An_{32}) 0.5 to 1.5 mm long and shows well-developed albite and carlsbad twinning. Pericline twinning can occasionally be observed. The intergrain boundaries are subrounded and slightly sinuous except where adjacent crystals have a common optical orientation (where the two (010) planes are subparallel), in which case the intergrain boundaries are straight. The feldspar is speckled with sericite and turbid with enclosed clay particles. Inclusions of limpid, rounded quartz 0.1 mm in diameter are sparsely disseminated in the plagioclase; but more commonly are seen inclusions of plagioclase 0.5 to 0.2 mm long whose optical orientation is oblique to that of the host. About 1% of the plagioclase contains epidote crystals 0.1 mm long which are anhedral but oriented with the longest dimension of the epidote parallel to the long dimension of the plagioclase. All plagioclase crystals contain blotches and laths of epidote 0.005 to 0.05 mm long which tend to be concentrated near the centers of the plagioclase crystals. Microcline in anhedral crystals up to one mm broad make up less than 1% of the rock. The microcline shows same kaolinization and sericitization as the plagioclase b ut epidote is conspicuously less well developed within it.

Epidote makes up 10% of the rock. Judging from its birefringence half the epidote is the iron-free variety clinozoisite and half is normal epidote (pistacite). There is variation of optical properties within some individual crystals, part of the crystal showing the low and anomalous birefringence of clinozoisite and part showing the stronger and normal birefringence of epidote. The crystals are ragged and embayed anhedra 0.1 to 0.5 mm broad containing inclusions of plagioclase which are in optical continuity with neighboring feldspar grains. The epidote occurs along crystal boundaries and generally at the intersection of several plagioclase crystals. Rarely the epidote occupies the centers of the plagioclase. It is also common as blebs and laths included in the plagioclase.

The mineral next in abundance to epidote is light green hornblende making 5% of the rock. It occurs in ragged laths 0.5 to 1.5 mm long. It is pleochroic from very light brownish-green to medium green. Most of the hornblende contains epidote inclusions which are elongate parallel to the c-axis of the hornblende, and a few hornblende crystals contain feldspar blebs which are optically continuous with neighboring feldspar crystals.

Green to colorless chlorite also makes up 5% of the rock. Eighty-five per cent of it is pleochroic from light olive-green to medium green, has birefringence about 0.004 and generally shows anomalous blue birefringence. It is observed in stubby, irregular flakes 0.1 to 1.0 mm broad with jagged terminations, and occurs interstitially among the feldspar crystals and is often associated in parallel growths with elongate grains of epidote and irregular grains of rutile. About 15%

of the chlorite is colorless to very light brownish-green and occurs in distinctly elongate flakes 0. 3 to 1. 5 mm long.

The quartz is interstitial in the plagioclase making up 15% of the rock. It conforms in some cases to the crystal outlines of the feldspar and has not been observed to show its own crystal outlines. It contrasts with the plagioclase in its lack of turbidity but in some rocks of the phase it includes needles of rutile up to 0. 03 mm long. The range is size of the quartz grains is from 0. 1 to 1. 5 mm in most of the chloritic diorite, but occasionally rounded phenocrysts up to 10 mm long are observed.

Rutile is sometimes the only accessory. It occurs in anhedral crystals and in trains of blebs rarely making up 2% of the rock. It tends to be associated with the chlorite and with the epidote, but also occurs in isolated grains between feldspar crystals. Rutile grains are occasionally as large as 0. 5 mm in diameter, but the usual range in size is between 0. 05 and 0. 1 mm. Other accessories observed are magnetite, ilmenite, calcite and clays.

The texture of the typical chloritic quartz diorite is medium phaneritic, hypidiomorphic-granular. The smaller crystalline mass is composed of subhedral plagioclase in grains 1. 0 to 1. 5 mm long, 0. 4 to 0. 7 mm broad, among which occur the anhedral quartz and mafic minerals. Disseminated in this groundmass are larger crystals of plagioclase which rarely attain 10 mm in length and more usually are two to five mm long. The ratio of phenocrysts to groundmass ranges from very small to 0.1, the most usual ratio being about 0.05, i.e., conspicuously larger feldspar crystals make up about 5% of the rock.

Fig. 7 (a)

Chloritic quartz diorite. The feldspar is highly sericitized and shows poorly developed albite twinning. The chlorite and epidote (stippled) are in very ragged flakes and grains. Camera lucida drawing, times 10.

Fig. 7 (b)

Chloritic quartz diorite. The fiel happens to show no quartz but illustrates the irregular grai boundaries and pervasive alterati (sericitization and kaolinization) which gives the texture of the roc a slightly confused appearance under the microscope. Camera lucida drawing, times 10.

TABLE 4

Mode of the Typical Chloritic Quartz Diorite (228" P)

Mineral		Range (%)	Average
Plagioclase	(An_{30} to An_{35})	55 - 65	60
Epidote	(Clinozoisite	0 - 10	5
	(Pistacite	0 - 10	5
Chlorite		5 - 15	5
Hornblende		0 - 15	5
Quartz		0 - 26	15
Muscovite-sericite		1 - 5	2
Microcline-orthoclase		0 - 5	1
Rutile and other accessories (including weathering products)		1 - 3	2

Variations

A wide range in composition and texture is included in the chloritic diorite phase of the pluton. The typical rock described above is representative of only about 70% of the rocks mapped as chloritic diorite. Thirty per cent is composed of rocks containing abundant chlorite or abundant epidote but in which pliagioclase ranges from 0% to 60%, quartz from 0% to 50%, and in which muscovite and biotite become important constituents and even scheelite becomes an important accessory. In those zones which have been mined as ores of tungsten scheelite in places makes up 2% of the rock. Textures range from felty (in the case of aggregates of muscovite with minor quartz) to granitoid and from medium to fine-grained. The bulk of the compositional and textural variants occur discontinuously near the contacts of the chloritic diorite with the sedimentary rocks. Isolated patches of atypical chloritic rock whose dimensions are measured in feet occur within the chloritic diorite, and these grade imperceptibly in a distance of one to three feet into typical or normal chloritic diorite.

A complete and quantitative discussion of the atypical rocks of the chloritic diorite phase would require mapping on a scale no smaller than 1:250, which was not done during this study. However, the diversity of the border rocks of the pluton can be illustrated by examples from two areas.

Phase near the A. M. W. Mine. Part of the contact of the pluton with the sedimentary rocks has been exposed in the search for tungsten at the A. M. W. Mine in Section 10, T. 9 N., R. 17 W. In the adits of the mine it can be seen that the contact is along a very irregular surface which is broken at intervals of several feet by faults of apparently small displacement. Much of the chloritic diorite in a zone within five feet of the contact is an olive green rock, finely phaneritic to aphanitic, in which occur irregular to rounded masses which resemble fine-grained granite. The olive-green groundmass is composed of a homogenous green matrix in which are disseminated white to colorless minerals in a serial range of size from 2 mm to the smallest which can be seen. The granitic masses appear to be composed of feldspar, chlorite and quartz, and to range in shape from distinctly rounded to angular to highly irregular. They are from 3 to 15 mm long and make up 10% of the rock. Under the microscope the groundmass is a structurless aggregate composed of quartz, feldspar, epidote, chlorite and calcite. Quartz makes up 60% of the goundmass in grains which range in size serially from the smallest visible to 2 mm in diameter. The quartz is anhedral and the grain boundaries are generally angular. Plagioclase (An_{28}) makes up 10% of the groundmass and is restricted to subhedral grains 0. 3 to 2 mm in length. Epidote and chlorite each make up 10% and are rare in grains larger than 0. 3 mm. The epidote is largely in anhedral grains 0. 05 mm in diameter, while the chlorite is in stubby to irregular flakes 0. 1 mm long. The calcite forms irregular areas, occasionally up to 3 mm long, of fine-grained aggregates. The granitic masses consist of quartz, plagioclase (An_{28}) and chlorite in the ratio 5:3:2. They resemble grandodiorite in texture except that (1) the quartz and plagioclase crystals tend to cluster separately to produce separated fields of quartz and of plagioclase; (2) the quartz is more embayed and sutured than is usual in a granodiorite; and (3) the mafic mineral is chlorite with accessory hornblende. The contrast in texture between the granodiorite masses and the groundmass is emphasized by a weak tendency for the boundary between the two to be free of the large crystals of the groundmass and by the development of chlorite flakes contiguous with and parallel to the boundary.

Figure 8 shows the texture of this rock.

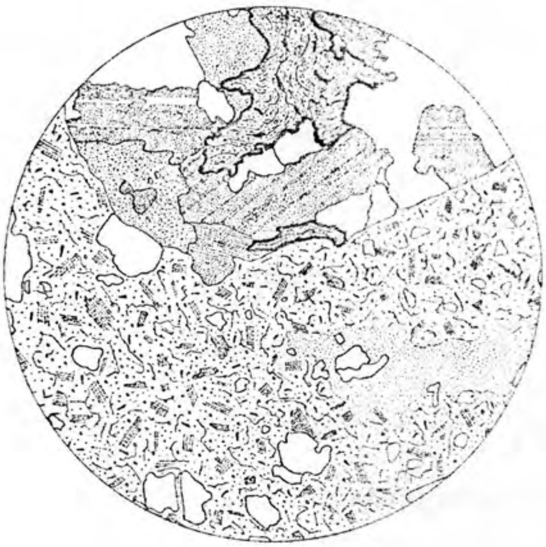


Fig 8

Chloritic quartz diorite variant at the "A. M. W." mine. The field shows the sharp boundary and contrasting texture of the aphanitic matrix (below) in which are masses of crystals with the texture and composition of granodiorite (above). Camera lucida drawing, times 10.

<u>Phase near the Magnitude Mine.</u> In Sec. 14, T. 9 N., R. 17 W., about 2300 feet W. S. W. of the Magnitude mine, the border of the chloritic quartz diorite is on the west side of a wash. Juniper forest and a thin mantle of cover hide most of the contact, but from isolated exposures the structure of the contact appears similar to that exposed at the A. M. W. mine. Within five feet of the location of the contact is an outcrop 6 feet long, 2 feet wide and 6 inches high of chloritic diorite. Macroscopically the rock is medium olive green, medium-grained and has a silky luster one associates with micaceous minerals. Under the lens the rock appears mottled by the intergrowth of green and gray constituents up to 2.5 mm long. Chlorite and muscovite appear to be the dominant constituents. Microscopically the rock is an intergrowth of felty muscovite in irregular elongate patches with green chlorite and quartz, in the ratio 5:3:2 respectively. In the felty patches the muscovite grains are between 0.05 and 0.1 long and are poorly oriented parallel to the elongation of the patches, which are between 0.5 and 4 mm long. The chlorite is pleochronic from light brownish-green to green and has very low birefringence in shades of Berlin blue to purple. It is present in irregular terminated flakes 0.5 to 2 mm long which contain minute grains of magnetite along the cleavage traces. Much of the chlorite is intergrown with muscovite

in parallel orientation. The quartz occurs in anhedral grains up to 4 mm long and in many cases is penetrated by the surrounding muscovite. Chlorite does not penetrate the quartz. Magnetite in grains 0. 05 mm in diameter is the principal accessory but minor epidote can also be seen. The texture of the rock is medium-grained and felty, but due to the intergrowth of parches of fine-grained muscovite with the medium-grained felty matrix made up of stubby crystals the fabric appears as a confused felty aggregate.

Inclusions

Small, more or less rounded enclaves of marked compositional or textural discontinuity, such as are frequently found in the quartz diorite or quartz monzonite, do not occur in the chloritic quartz diorite. The manner of variation is gradational and generally on a scale which is measured in feet rather than inches.

Sedimentary inclusions. Inclusions of what is thought to have been sedimentary rock are conspicuous. However, they undoubtedly make up less than 0. 1% of the area mapped as chloritic quartz diorite. They are concentrated in a zone generally less than 100 feet wide next to the contact of the pluton with the sedimentary rocks.

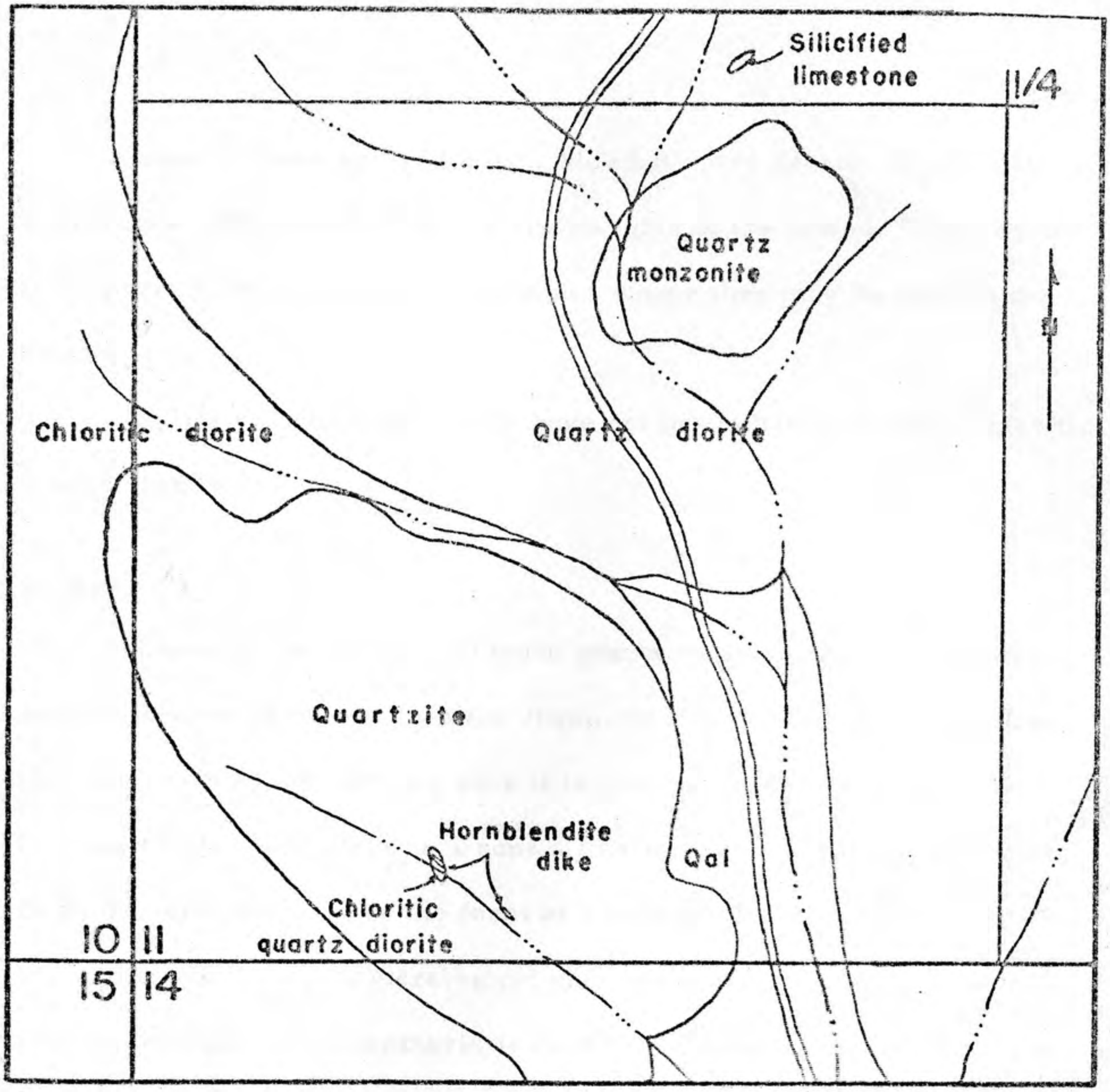
Two particularly large inclusions 500 feet long, 60 feet wide, of sandy limestone are located near the A. M. W. mine in Sec. 10, T. 9 N., R. 17 W. They are silicated in a zone ten feet wide adjacent to their abrupt contacts with the plutonic rock. Locally scheelite is disseminated in commercial amounts in the zone of silicification. Elsewhere in the area there are much smaller inclusions recognizable as former limestone and now composed either of calcite and quartz or of actinolite, diopside and wollastonite. The inclusions are generally elongate, measuring no more than four to six feet. Their bedding, where it can be discerned, is parallel to the length of the inclusion but not necessarily parallel to that of the adjacent sedimentary rock.

Inclusions of former sandstone or quartzite are much more difficult to see than limestone inclusions in the plutonic rock. They appear to be less abundant than limestone inclusions, and only four were found. The quartzite is high in chlorite and feldspar and under the microscope there is no evidence of clastic structure. The quartzite inclusions are similar to the limestone inclusions in size and in having apparently sharp contacts with the plutonic rock, but none were found well enough exposed for detailed study of the contact.

On the west wall of Willow Wash, in Sections 11 and 14, T. 9 N., R. 17 W., there is an enclave of quartzite which has an area of 80 or more acres broken by several patches of 100 square feet of chloritic quartz diorite. However, in a gully which dissects the quartzite there is an area 60 feet long and 15 feet wide in which chloritic diorite crops out, and near the center of the diorite is a hornblendite (4112) dike two feet wide. Figure 9 sketches the relationship. The dike is of a dark green, fine-grained rock composed of hornblende (70%) in ragged laths 0. 1 mm long and chlorite (30%) in broad flakes 0. 2 mm long, with virtually no felsic minerals.

Dikes

Quartz veins up to six inches wide and exposed for several feet along their strike are not uncommon in the chloritic quartz diorite. They tend to occur in groups of two, three or four with a parallel or echelon arrangement. About 2100 feet south and 300 feet east of the N. W. corner of Section 13, T. 9., R. 17 W., there is a particularly large quartz vein is 3 feet wide that encloses laths of epidote up to 2 inches long and 1/4-inch thick which make up 5% of the vein. The epidote has low and anomalous birefringence. Adjacent to the sharp contacts of the vein the wall rock shows great variation in texture and composition and has a chaotic structure interpreted as the effect of faulting parallel to the vein. Horses of the wall rock two to three feet broad are normal chloritic quartz diorite, quartz diorite and clinozoisite rock (clinozoisite 80%, quarrz 20%). This locality was the only one where strong epidote mineralization was encountered, although epidote frequently makes up an essential part of the chloritic quartz diorite.



SKETCH MAP

of the

SOUTHWEST QUARTER of SECTION 11, T. 9 N., R. 17 W.

0 500 1000 1500

FEET

Location of Hornblendite Dikes

FIG. 9

Calcite veins up to 1/2-inch wide but more usually 1/4-to 1/16-inch wide occur within several feet of the margins of the pluton. They appear to be rare except at the A. M. W. mine, where they may be seen in the adits.

Aplite and pegmatite dikes have not been observed in the chloritic quartz diorite.

Contacts

The contact between chloritic quartz diorite and the surrounding sedimentary rock in some places sharp, in others gradational. Where the contact is with carbonate rock it is generally sharp, although decomposition of both rocks in a zone a foot wide may mask the relations. Gradational contacts take the form of a zone of bleaching of both carbonate and diorite. The mineralogical phenomena which give the zone of interpenetration its characteristic aspect is the development of a light-colored scarn (mica, wollstonite, tremolite, diopside and quartz). Such bleached zones are up to 15 feet thick and in the vicinity of the A. M. W. and Magnitude mines are the site of tungsten mineralization.

The contact between chloritic quartz diorite and quartzite is rarely sharp. Approaching from the quartzite to the chloritic quartz diorite one sees in the field that the rock becomes increasingly flecked with mafic minerals. Continuing toward the diorite the grains of which the quartzite is composed becomes larger and finally the rock no longer seems to require the appellation "quartzite," but rather "leuco-diorite." Such zones of transition are approximately ten feet wide but vary locally from two to fifty feet. Under the microscope feldspar can be seen replacing the quartz in the manner described by Stringham (1952). Figure 9 shows the relationships.

The contact between chloritic diorite and quartz diorite or quartz monzonite is invariably gradational over a distance of 10 to 20 feet. The difference in the field between the phases is one of color tone which cannot be sharply defined. The major mineralogical distinction is based on the relative amount of chlorite, secondarly on the relative amount of epidote, and these minerals are present in the border facies of all plutonic phases.

Lamprophyr Dikes

Distribution

Lamprophyr dikes are found in the sedimentary rocks along the ridge-top of the southern Grouse Creek Mountains north of North Rocky Pass, and scattered in Bovine Mountain. Two large lamprophyr dikes occurs isolated from others in Sec. 35, T. 10 N., R. 17 W. On the ridge-top the dikes occur in groups of two or three exposures within

100 to 300 feet of each other, and the groups are separated from each other by about half a mile along the strike of the ridge. In Bovine Mountain the lamprophyrs are scattered from Emigrant Wash to the east side of the mountain, with an average concentration of one lamprophyr sill or dike per square mile. The dike groups on the ridge-top and in the pluton are indicated on Plate I. Those found in Bovine Mountain have not been represented. No lamprophyr dikes were found in the pluton. The location of the hornblendite dike in Sec. 11, T. 9 N., R. 17 W., is indicated in Figure 2, and discussed with the chloritic quartz diorite. The two meladiorite dikes near the Magnitude mine are indicated on Plate I. Two hundred feet south of these, in the Eureka(?) quartzite, is a dike 5 feet broad and 15 feet long composed of muscovite and chlorite making up 65% and 25% respectively with interstitial quartz making up 10%. This dike appears to be a variant of the chloritic quartz diorite phase of the pluton and is an apophysis in the form of a dike.

Description and Variations

Ridge-top lamprophyrs. The lamprophyric rocks of the ridge-top form circular outcrops ranging in diameter from 15 to 40 feet, suggesting that the bodies have the form of plugs in the limestone and sandy limestone. The rock is massive, dark olive-green and weathers into angular blocks two to three inches broad. In the hand specimen individual mineral grains can barely be distinguished with the naked eye. Under the microscope rock is seen to be composed of andesine (60%) and hornblende (30%) with minor quartz calcite, sericite, epidote, chlorite, magnetite and clay. The andesine forms a background of subhedral crystals 0.05 to 0.2 mm long. Zoned extinction is visible in the larger crystals, which generally have sericitized cores. Hornblende is medium green and in laths and needles up to 0.3 mm long but averaging 0.1 mm in length. Quartz is interstitial and makes up about 5% of the rock. The texture is distinctly lamprophyric. The rock is a spessartite (2212). The northernmost lamprophyr group indicated on Plate I, in Section 13, T. 10 N., R. 17 W., resembles the others megascopically but chlorite is the principapl mafic mineral and the texture of the rock is fine-grained panallotriomorphic rather than lamprophyric.

Lamprophyrs in Section 35. The large lamprophyrs in Sec. 35, T. 10 N., R. 17 W., occur as dikes in the Guilmette limestone. The southeasternmost is more than 200 feet broad and 700 feet long; the northwesternmost is 75 feet broad and 250 feet long. They are composed of similar rock, camptonite (2212), which has a light to medium apple-green matrix in which needles and laths of hornblende up to 10 mm long are scattered without preferred orientation. The groundmass is composed of very highly sericitized feldspar which appears to be principally oligoclase in subhedral grains up to 0.7 mm long. Quartz in rounded and in some cases embayed grains 0.1 mm broad fills the interstices between feldspar crystals along with minor epidote, calcite and ilmenite. Light olive-green hornblende, only slightly pleochroic in shades of olive-green, forms laths up to 10 mm long in the matrix.

Dikes in Bovine Mountain. In Bovine Mountain there are dikes, sills and plugs in the sedimentary and metamorphic rocks which are composed either of dark green or medium brown rock. They have not been observed to be larger than 10 feet broad and when in the form of dikes or sill can sometimes be traced discontinuously for 75 feet. The most usual size of the outcrops is 5 by 15 feet. The brown rock has always been found in the form of sill, the dark green rock as sills, dikes or plugs. Three outcrops of brown rock and seven of dark green were found, but it seems likely that more exist since the outcrops are inconspicuous and no search was made for them.

The brown sills are of porous, somewhat incoherent rock composed of calcite, muscovite, quartz, plagioclase, chlorite, limonite and magnetite, decreasing in abundance in the order named. Calcite grains rarely attain 0.2 mm in bredth and the grain size of all constituents is generally less than 0.1 mm. Texturally the brown rock is seen as a confused aggregate since the constituent minerals are about the same size as the thickness of a thin section, there is much overlapping of grains, and opaque to cloudy limonite obscures the boundaries between grains.

The dark green rock is coherant and not porous. It is typically composed of needles 0.1 to 0.3 mm long of brown (basaltic) hornblende in a matrix of subhedral plagioclase crystals 0.1 mm long. Rhombic and rectangular areas of exceedingly fine-grained sericite and calcite and of yellow-green serpentine suggest the former presence of plagioclase phenocrysts. A suite of specimens collected to reveal the internal structure, zoning or contact effects of a dike showed that in this particular case the dike rock is sensibly the same in composition and texture at the interior and the edge of the dike and that the limestone which it cuts shows no contact effects visible microscopically. There is, however, a zone about 1/2-inch wide of gouge-like material between the dike and the limestone of which it was not possible to make preparations for microscopic study. The dikes in Bovine Mountain appear to be spessartites (2212) or altered spessartites.

CONTACT METAMORPHISM

In the southern Grouse Creek Mountains the following four types of contact effects have been observed: (1) Formation or recrystallization of quartz in veinlets and disseminated blebs in limestone and dolomite; (2) silication of carbonate rocks by the formation of the silicates diopside, actinolite (or tremolite), wollastonite and forsterite; (3) feldspathization of quartzite, i. e., the formation of feldspar at the expense of quartz and, generally, concommitant formation of biotite; and (4) the formation of textural variations in the sedimentary rocks around the border of the pluton.

Along about 50% of the contact of the sedimentary rock with the pluton there are no perceptible contact effects. So far as can be observed the granitic and sedimentary rocks abut along a sharp contact. In many places, however, the actual contact is obscured by a mantle of cover, so that what appears to be a sharp contact may be gradational on a scale of inches.

Formation of Quartz

Silicification of the type described under (1) above is not uncommon along the contact of carbonate rocks with the pluton. In such rocks the quartz appears as small (0. 1 mm) grains making up veinlets up to 0.5 mm broad or as patches of small grains or as disseminated anhedral grains. Under the microscope it is seen that in the vicinity of the quartz the carbonate is recrystallized into very fine-grained aggregates which may in patches be so fine grained as to be microscopically cyptocrystalline. The very fine-grained calcite is a feature which the sediments lack away from the contact, as are the veinlets of quartz. The presence of these features near the contact suggests to the writer that recrystallization has occurred and that, probably, some silica has been introduced. Silicification of this sort is generally confined to a zone less than five feet wide at the contact. Rarely such zones are found to extend 50 feet from the contact. It is shown by the Guilmette limestone in the southern portion of Section 6, T. 9 N., R. 16 W., and also by limestone further to the east in Sections 8 and 9. The Simonson dolomite is silicified by the introduction of silica where it is in fault contact with the pluton in Section 12, T. 9 N., R. 17 W.

Formation of Silicates

Silication of carbonates by the formation of a scarn of diopside, actinolite (or tremolite), wollastonite or forsterite has been a minor process around the pluton. It has taken place in calcareous inclusions as previously mentioned. Isolated beds, some as much as 600 feet from the contact have also been altered in this way. No lime silicate beds were found abutting on the pluton. At the Compressor mine the Simonson dolomite has been silicated at a distance of 35 feet from the contact by the transformation of a 40-inch carbonate bed to a fine-grained mixutre of actinolite and wollastonite in which occur slightly larger anhedra of diopside. Sheelite also occurs in this bed and mining operations have created a particularly good exposure in which the relation of the silicified bed to the pluton may be seen. On the northwest wall of Willow Wash, at a distance of about 350 feet from the pluton, occur pods 1 x 3 inches in size of bladed tremolite. Further to the west, in the midst of an exposure of unaltered limestone 4 feet thick is a three-inch bed of actinolite rock. In the Simonson formation, 1600 feet south and 900 feet west of the northeast corner of Section 11, T. 9 N., R. 17 W., there is a poorly exposed bed of carbonate rock apparently about 5 feet thick. The bed is composed of calcite and dolomite in about equal proportions making up 65% of the rock, forsterite in elongate rounded grains 0.08 mm long making up 30% and chlorite making up 5%. Most curious of all such altered rocks was one found on the east side of Bovine Mountain (Section 21, T. 9 N., R. 16 W.) in the fault zone which separates the fusulinid-bearing Strathearn beds from the Precambrian ones. Here a small boulder was found which superficially resembles light gray limestone populated by dark gray fusulinids making up 10% to 15% of the volume of the rock. Close examination shows the "limestone" is a mixture of tremolite and wollasonite and that the "fusulinids" are diopside phorphyroblasts. Furthermore, the diopside porphyroblasts contain, in some cases, dusty centers. The source bed of this curious boulder was not found.

Feldspathization

Feldspathization of quartzite is widely developed in the vicinity of the quartz diorite in Willow Wash. It has already been mentioned that the effect is so extreme that it is sometimes difficult to distinguish the contact between quartzite and pluton and that similar feldspathization occurs on a small scale near Rocky Pass. Biotite and/or chlorite appear as feldspar develops and increase in amount as feldspar increases. No feldspathized quartzites were observed which lacked either biotite or chlorite. The phenominon is apparently entirely similar to the feldspathization of quartzite at Bingham Canyon described by Stringham (1953). Stringham found that the replacement of quartz by feldspar was partly governed by the crystallographic planes of the quartz. Figure 10 shows similar control by quartz in the southern Grouse Creek Mountains. Like the interstitial, replacing feldspar at Bingham, the feldspar network found near the chloritic quartz diorite is in large crystals. In the illustrated field, taken without modification from a camera lucida drawing, the feldspar network is composed of a single plagioclase cyrstal.

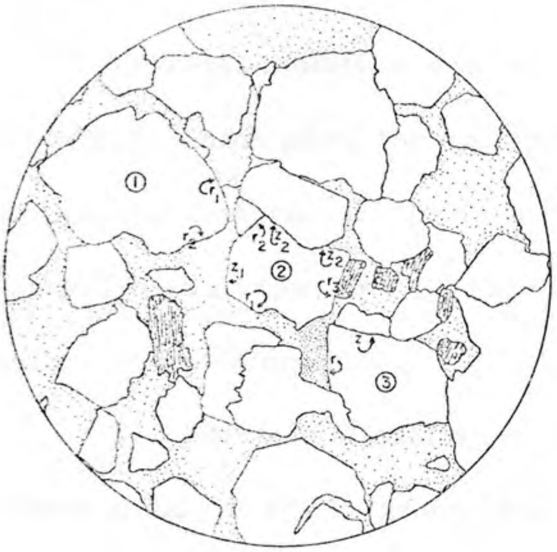


Fig. 10 (a)

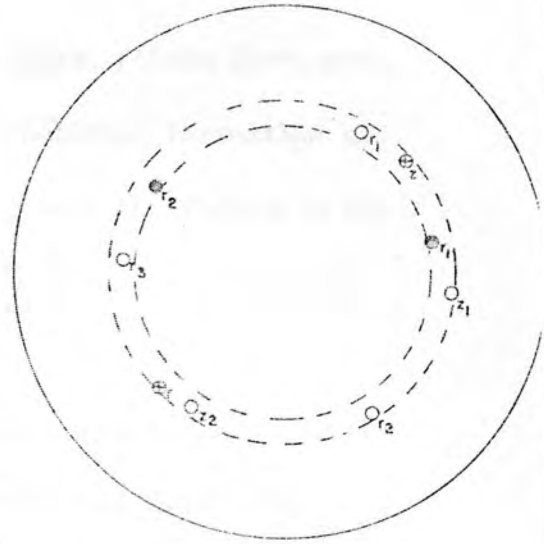


Fig. 10 (b)

Transition rock between the quartz-ite and the chloritic quartz diorite in Willow Wash. Note the subhedral boundaries of the quartz grains which are enveloped by a single crystal of oligoclase in which (010) is almost parallel to the plane of the drawing; the mafic mineral is chlorite. Camera lucida drawing, times 20.

Stereographic projection (lowe hemisphere) of the poles of th grain boundaries indicated in Fig. 10 (a). Closed circle crystal No. 1; open circles, crystal No. 2; crossed circles crystal No. 3 For each cryst the optic axis of the quartz ha been rotated to the center of th diagram and the plotted poles o the grain boundaries correspon ingly rotated. The dashed line are 4° from the line upon whic the poles of rhombohedral faces should fall if all measurement were perfect.

Textural Modifications

Textural modifications are of three sorts, (1) the formation of hornfels which gives the quartzite of the Chainman formation a saccaroidal texture, (2) the formation of a granulitic texture in the Eureka(?) quartzite, and (3) the development of a corase-grained texture in limestone.

The hornfels alteration of the Chainman quartzite has been observed only in the large enclave of Chainman and Guilmette formations to the east of Rocky Pass. Along the line separating Range 16 from Range 17 West hornfels is developed in lenses parallel to and bordering the contact. The lenses are no longer than 50 feet, no wider than 30 feet, and are discontinuous. Andalusite porphyroblasts occur in the hornfels. Most of the contact is with uneffected quartzite, which is the case elsewhere that the Chainman formation is in contact with the pluton. The Eureka(?) quartzite is nowhere altered to hornfels.

Along a few tens of feet of the contact exposed on the east slope of Citadel Peak the Eureka(?) quartzite has a granulitic texture without feldspathization or an increase in grain size.

In the locality already referred to on the east of the pluton between Rocky and North Rocky Passes, where the granitic rock is "interbedded" with limestone, the carbonate has a granitic but slightly schistose texture. The average grain size is greater than one millimeter. Elsewhere perceptible but not extreme increases in grain size mark the contact between the pluton and the surrounding limestones.

STRUCTURE

General Statement

The structure of the sedimentary rocks of the southern Grouse Creek Mountain is that of a major horst with an internal, faulted anticline bounded on the east and west by synclines. The plutonic rocks transect the anticline and synclines without notably participating in or affecting their structure. The horst is veneered on its borders by poorly consolidated erosional debris and volcanic rocks.

For descriptive purposes the area may be divided into eight parts, each with its own dominant structural feature.

1. The eastern fault block, including the Precambrian formation and the Paleozoic sedimentary rocks to the east of it.

2. The Bovine Mountain syncline, which makes up the central portion of Bovine Mountain.

3. The Bovine Flat anticlinal fault complex, which forms the west and southwest slopes of Bovine Mountain.

4. The central syncline, whose limbs dip toward Willow Wash.

5. The Rocky Pass area, between Citadel Peak and North Rocky Pass.

6. The ridge area, lying north of North Rocky pass.

7. The Traissic anticline, to the west of Rocky Pass.

8. The Genozoic area, which includes the southern and western foothills of the southern Grouse Creek Mountains.

Figures A and B of Plate II represent diagramatically the structure of the area. It will be noticed that they portray the pluton as terminating with depth in accordance with the hypothesis presented below. In the construction of the cross sections it is further assumed that horizontal section represented by the surface of the earth is relatively near to the base of the pluton, and that faulting exercised strong control over the location of the pluton.

Eastern Fault Block

The eastern fault block is composed principally of the Bovine formation, a ridge of the Strathearn formation and a large outcrop of the red quartz monzonite. It forms a south-trending strip included almost entirely in Sections 10, 15, 22, 27 and 34, T. N., R. 16 W. A crosssection of the northern part of the area is represented on the eastern (right) portion of Plate II and its structural evolution portrayed in Plate IV.

The phyllite unit of the Precambrian is thought to be correlative with part of the Proterozoic series exposed at the southern end of the

Promentory Range. If this is the case one is obliged to postulate either normal faulting of unbelievable magnitude or thrust faulting to bring the Precambrian formation to its present position. Thrust faulting is a reasonable mechanism since thrusting has been recognized to play a role in the structural evolution of southeastern Idaho and northcentral Utah (see summary by Eardley (1952) pp. 320-330).

Protruding from the Quarternary lake gravels which mantle the eastern flank of Bovine Mountain are isolated, subdued inselberge made up of silicified limestones and dolomites and of quartzites. Only one of these has been positively identified palaeontologically, and it belongs to the Silurian Laketown formation. The others are so much shattered and recrystallized that formational lithologies could not be recognized. However, from the existence of the inselberge and of Basin and Range faults which presumably border the mountain on the east, it is inferred that a zone of en echelon faults trends southwestward following the diagonal of Sections 24, 26, and 34, T. 9 N., R. 16 W.

Bovine Mountain Syncline

The dominant structural feature of the eastern two-thirds of Bovine Mountain is a syncline which plunges southward at about 20 degrees. The syncline is bounded by parallel south-trending faults on the east and west. Since the western fault has thrown the Guilmette fromation against the Chainman in one place, it has a probable displacement of 1000 feet. The eastern boundary fault is probably also a normal fault.

The syncline is bounded on the north by fault blocks made up of sediments whose attitudes conform, in a general way, with the configuration of the syncline, indicating that the blocks are set off by faults of relatively small displacement. These blocks, cropping out largely in Section 16 and 17 of T. 9 N., R. 16 W., are considered a part of the Bovine Mountain synclinal structure. On the north where they are bounded by plutonic rocks they show contact effects, and elsewhere they are mantled by conglomerate of the Tertiary unidentified formation. On the northeast the syncline is in contact with the red quartz monzonite. The northward extension of the syncline's eastern boundary fault forms the line of contact between the sediments and the pluton, and suggests that the fault probably influenced the emplacement of the pluton. On the south the Bovine Mountain syncline is in fault contact with a southeastward projecting tongue of the Bovine Flat complex.

Bovine Flat Anticlinal Fault Complex

The Bovine Flat anticlinal fault complex is a belt about 1-1/2 miles wide which extends southeastward on the east and south of the Bovine Mountain syncline. It is composed of blocks of the Silurian, Devonian, Mississippian(?) and Pennsylvanian-Permian formations which have been in some places greatly contorted. The blocks are bounded by faults whose attitudes show no strong preferred orientation, although there is a tendency for the faults to be aligned slightly west of south and north of west.

Warping, folding and minor faulting is characteristic of the sedimentary rocks within the individual fault blocks. Attitudes of the sediments range from nearly horizontal to overturned. Three of the twenty-five or more blocks of which the belt is composed are made up largely of vertical sedimentary strata. The individual fault blocks are broken by more faults but of small displacement and productive of much brecciation. Slickensides are widespread. In Emigrant Wash horizontal Guilmette limestone can be seen resting on and entirely surrounded by vertical limestone of the same formation. Nearby, gently dipping Guilmette limestone rests on black shale of the Chianman formation. These anomalies probably represent the remains of an originally more extensive decollement; they are not interpreted as evidence of great lateral pressures, although conceivably might be part of the postulated Proterozoic thrust slice east of the Bovine Mountain syncline. In favorable exposures one can see overturned and recumbent folds in the strata of the fault blocks. Two such folds are well exposed on the valley wall to the east of the easternmost remnant of the decollement, which is conveniently accessable from the country road leading through Emigrant Wash.

The southeasternmost exposures of the Bovine Flat complex are made up of very much faulted, silicified and brecciated rocks whose assignment to one or another formation is difficult. On the basis of lithology and general aspect they have been questionably correlated with the nearby Ordovician, Silurian, Devonian and Mississippian(?) sediments.

On the north the Bovine Flat complex is bordered by gray quartz monzonite and shows contact effects attributable to the formation of the pluton. On the west it merges without definite boundary in the vicinity of Emigrant Wash with what is described below as the central syncline. On the southwest it is bordered by the Tertiary unidentified formation, on the south by Quarternary lake gravels. The eastern contact is with the Bovine Mountain syncline.

Central Syncline

The central syncline is the field name given to the tongue of plutonic rock and associated sediments which crop out in and about Willow Wash and which merge without definite boundary on the north with the rocks of Rocky Pass.

The core of the syncline is made up of quartz diorite whose outcrop is elongate toward the southeast. Bordering the quartz diorite is chloritic quartz diorite on the west, quartz monzonite on the east. The Ordovician(?) sediments on the west and the Devonian-Mississippian(?) ones on the east (already referred to as part of the Bovine Flat complex) dip generally toward the diorite, giving the structure its imperfect synclinal form.

The plutonic core of the central syncline is divisible petrographically into the phases already described. The distribution of these does not follow a simple pattern since there are enclaves of one in another and outlayers of chloritic diorite in the sedimentary limbs of the syncline, as well as inclusions of sedimentary rock within the pluton. The area is one of great complexity as seen in man-made cuts and shafts, and slickensided outcrops attest to widespread minor intraformational faulting. The outcrop pattern of the plutonic rocks resembles the pattern of a slice of poorly mixed marble cake, and the subsurface structure is probably a three-dimensional analogue of this pattern.

The sedimentary rock contiguous with the pluton on the west and south of the synclinal tongue is quartzite questionably referred to the Eureka formation. At most exposures it dips gently toward the pluton, but local reversals in dip, due to faulting, are not uncommon.

A major south-trending fault zone occupying the bed of Willow Wash is postualted to account for the broad outcrop of the quartzite south of the Magnitude Mine. The field evidence for such a fault is ambiguous; it consists largely of slickensided quartzite knobs exposed protruding through a mantle of plant and rock cover. If such a fault exists, the pluton of the syncline occupies a fault zone.

On the north the plutonic rock of the central syncline abuts against Devonian strata which show contact effects already described. The Ordovician(?) rocks which make up the west limb of the syncline are faulted against Devonian to the north and mantled by Tertiary conglomerate on the west. In one locality (not shown on Plate I) a small (10- by 30-foot) bed of lithic tuff may be seen resting on Ordovician(?)

limestone and in turn overlain by conglomerate. On the south the decollement already mentioned obscures the relations between the Ordovician(?) and Mississippian rocks. It appears that a complexly faulted zone is almost completely covered by the decollement.

Rocky Pass Area

The Rocky Pass area, which includes the rocks which crop out between Citadel Peak and North Rocky Pass, consists of a more or less homogenous plutonic mass in contact with fault blocks of Ordovician(?) and Devonian strata. Red quartz monzonite forms two tongues of plutonic rock which project into the surrounding sedimentary country rock and make the outline of the pluton very irregular. Dikes of gray quartz monzonite cut both limestone and quartzite in the vicinity of North Rocky Pass, and two large lamprophyr dikes occur in the limestone between Rocky and North Rocky Passes. No faulted contacts were found between the pluton and the surrounding sedimentary rocks. The western boundary of the Rocky Pass area is the fault which places Ordovician(?) against Triassic rocks. This fault has a throw no less than 5500 feet and is natural structural boundary. The northern, southern and western boundaries of the area are indefinite but for descriptive purposes are taken at North Rocky Pass, Citadel Peak and the country road respectively.

Protruding as rounded inselberge through the Quaternary cover on the east side of the range are four exposures of Devonian and Mississippian strata. Each has an area of about one square mile, a more or less uniform dip toward the northwest and displays the ubiquitous slickensided outcrops which indicate general if small scale faulting. The dip of the strata of the inselberge is contrary to that of the beds at North Rocky Pass, suggesting that a major fault, now buried by alluvum, separates the inselberge from the rocks of North Rocky Pass and those of the crest of the range.

The inselberg which occupies most of Section 31, T. 10 N., R. 16 E., is in part in contact with the pluton and in part surrounded by alluvium. It may be that this mass, and less probably the others, is a large enclave of sedimentary rock in the pluton.

A fifth inselberg, which forms a continuation of the chain of inselberge described above, is exposed in the northeast corner of the mapped area. It is composed of white quartzite in which occur at intervals of about 15 stratigraphic feet beds two inches thick of crumpled biotite. On lithologic grounds this formation is referred to the Proterozoic and a fault now buried by alluvium, is postulated to account for the proximity of Devonian strata. A straight scarp, interpreted as a fault line scarp, marks the contact between the quartzite and

Tertiary sediments which form part of the inselberg. Possibly the quartzite is part of the same thrust sheet exposed in the eastern fault block.

Ridge Area

The ridge top of the Grouse Creek Mountains north of North Rocky Pass is made up of blocks of strata dipping generally northwest. The bounding faults of the blocks trend almost parallel to the strike of the strata, and northward repetition of the Devonian and Mississippian beds has occurred.

On the west Tertiary sediments lap over the Paleozoic rocks almost to the crest of the range. On the east alluvium forms broad meadows between the bedrock of the ridge area and the rounded inselberge. High Tertiary conglomerate on the west and alluvial meadows on the east suggest Basin and Range block faulting parallel to the east side of the range. To the south the elongate fault blocks of the ridge area terminate against a fault which crosses the range north of the North Rocky Pass. Northward the fault block structure appears to persist until it abuts against the Muddy Creek pluton about four miles north of the mapped area.

Triassic Anticline

In Rocky Pass canyon, on the west side of the pluton, Triassic rocks are exposed as a west-trending asymmetrical anticline. The strata north of the canyon dip uniformly 40 degrees to the north. Those on the south of the canyon dip at varying inclinations gently toward the south-southwest. The floor of the canyon marks the site of a fault parallel to the axis of the anticline along which rupture has occurred. Weakly consolidated Cenozoic sediments mantle the Triassic rocks on all sides except the east where the Triassic rocks are in fault contact with Paleozoic rocks.

The fault which throws Triassic against Ordovician(?) rocks must have a displacement measured in thousands of feet; nonetheless, it is one of the least conspicuous in the field of the major faults in the southern Grouse Creek Mountains. It illustrates a peculiarity which is common in the region, viz., that small intraformational faults are made conspicuous by a narrow zone of brecciation, by silication or by slickensided boulders and outcrops. Large faults are inconspicuous because they produce broader zones of brecciation which weather to blend with the general cover of float or which form stream valleys and become mantled with alluvium.

A small section of Triassic rock dipping 20° southeast protrudes through the Cenozoic sediments in Section 9, T. 9 N., R. 17 W. It appears to be cut off by a fault on its west side but the mantle of Cenozoic sediments obscures its contacts with consolidated bedrock.

Cenozoic Area

Surrounding the southern Grouse Creek Mountains on the east, south and west are more or less flat-lying, poorly consolidated sediments. They lie like a blanket over the margins of the range and make up its foothills. Although in isolated localities they are tilted as much as 45°, they deviate in most places no more than ten degrees from the horizontal. Steep tilting is particularly characteristic of the lithic tuff vitrophyr units in the northwest corner of T. 9 N., R. 17 W. Undoubtedly the steep dips are due in part to faulting, but the weak consolidation of the units permits the formation of thick cover which masks the sites of the faults. Possibly as important as faulting in the formation of dipping beds is primary flow banding. The vitrophyrs are so varied in aspect (color, coherance, fracture) that they appear to be made up of many separate, small extrusions from local vents. Consolidation of viscous lava from separate vents would produce topography of some relief to which younger extrusions would have to conform.

The aggregate, when dissected, would show isolated beds of steep and random dip.

Faults have been observed in the Cenozoic sediments but none were found traceable for more than a few tens of feet due to the cover which forms in their weathering. Exposures are so poor that even where long faults of large displacement were suspected, discontinuous exposures along the supposed strike of the faults could not be found.

Joints

The attitudes of the joints of the plutonic and sedimentary rocks around Rocky Pass were measured and plotted in stereographic projection. The projection pattern which emerged from more than 100 determinations was isotropic, and further efforts to correlate the joint pattern with the attitude of the sediments and the features of the pluton were abandoned.

Although the pattern of the joints as a whole is isotropic, there is a weak tendency of the major joints of the pluton to strike a few degrees east of north. Such jointing is particularly strongly developed in the pluton to the northeast of Emigrant Wash, but may be observed to the west at Rocky and North Rocky Passes and also in the red pluton northeast of Bovine Mountain. The dip of the north-trending major joints is nearly vertical, dipping slightly eastward on the west, westward on the east. No such alignment of major joints is visible in the sedimentary rocks contiguous with the pluton.

GEOLOGIC HISTORY

Proterozoic Era

The phyllite unit and the quartzite unit in Section 14, T. 10 N., R. 16 W., represent the Proterozoic rocks of the southern Grouse Creek Mountains. They are thought to be allochthonous but possibly have not been moved more than twenty or thirty miles. They are lithologically similar to the rocks of the Raft River Range described by Felix (1956) and probably have a similar history, viz., deposition in a shallow seaway.

Paleozoic Era

The Grouse Creek Mountains occupy part of the site of the Rocky Mountain miogeosyncline (Kay (1951)) of the Paleozoic Era. The geosyncline was a basin largely of carbonate deposition which throughout its history underwent epochs of gentle diastrophism. The gentle epirogenic movement was interrupted by the Antler orogeny, which occurred early in the Pennsylvanian period (Roberts, et al (1958)). Evidence of this orogeny in the southern Grouse Creek

Mountains consists of the beds of pebble conglomerate which occur in the upper part of the Chainman-Diamond Peak formation in Bovine Mountain. The quartzite which forms the base of the formation at North Rocky Pass may reflect distantly the orogeny. No angular discordance of the sedimentary rocks records the orogeny in the southern Grouse Creek Mountains.

Mesozoic Era

Rocks equivalent in age to the Thaynes group of north-central Utah indicate that the Rocky Mountain geosyncline persisted in the area of the southern Grouse Creek Mountains to the beginning of Middle Triassic time. The relations between the Triassic rocks of the area and the underlying Permian ones were not observed. Elsewhere the relations are disconformable, but Wheeler et al (1949) say that the "stratigraphy near Spruce Mountain, Nevada, proves the continuity of Permian and Early Triassic seas across Utah into northwestern Nevada." Rock of marine origin representing the Jurassic and Cretaceous periods are unknown in northwestern Utah. The area was presumably a highland undergoing erosion. Van Houten (1956) identifies a conglomerate bed which crops out six miles east of the mapped area as possibly Cretaceous, corresponding to the Cretaceous(?)

conglomerate mapped by Christiansen (1952) in the Canyon Range. If this conglomerate is Lower or Middle Cretaceous it represents a phase of the Cedar Hills orogeny in the area of the Grouse Creek Mountains. If late Upper Cretaceous it reflects the Laramide orogeny.

Cenozoic Era

General Statement

From favorable exposures in the Basin and Range province a relatively complete history of the region has emerged (cf. Nolan (1953) and Eardley (1951) and Van Houten (1956)). The province was apparently the site of local continental and lacustrian sedimentation associated with faulting and vulcanism. That the plutons of the province are largely associated with the Laramide orogeny (Upper Cretaceous to Eocene) has been confirmed by radiometric determinations. Thus the Alta stock (Crittenden (1952) and the Silver City stock (Morris (1957)) have been determined to be late Eocene and middle Eocene respectively, although the Sheeprock stock (Cohenour (1957)) is Miocene.

Southern Grouse Creek Mountains

Guided by the general history of the region it is possible to deduce the probable history of the southern Grouse Creek Mountains with some confidence. The pluton postdates the trusting of the Precambrian phyllite and quartzite since the plutonic rock is "interbedded" with the phylite unit in Section 24, T. 9 N., R. 16 W. The thrusting post-dates the major folding since the Precambrian rocks appear to mark only a minor break in the eastern limb of the Bovine Mountain syncline, and the Strathearn(?) formation to the east of the Precambrian participates in the synclinal structure. The evidence on the east side of Bovine Mountain therefore suggests (1) folding, (2) thrusting, and (3) formation of the pluton.

On the west side of Emigrant Wash the border of the pluton is remarkably straight for a distance of 1-1/2 miles, although it shows evidence in places of contact effects. In some places around the contact of the pluton, particularly where exposed in man-made excavations, the pluton contains shear zones marked by limonite staining or even tungsten mineralization. These two facts are interpreted by the writer to suggest that normal faulting took place concomitantly with the formation of the pluton. It therefore seems likely that the major structure was modified by faulting and possibly also by attendant folding during the formation of the pluton. The writer believes that probably the Bovine Flat anticlinal fault complex was broken into its characteristic block structure during this epoch.

There is no direct evidence concerning the age of the pluton except that it is post-Permian and pre-Pliocene. Lacking radiometric data it is necessary to assume that its age is similar to that of similar plutons whose ages have been determined. On this basis it is likely Eocene, and the pre-pluton folding and thrusting is probably Laramide. From the field evidence, however, it is not possible to say definitely that the development of the structure of the Grouse Creek Mountains did not begin as early as early Cretaceous, and extended intermittently until Eocene or even Miocene time.

A second episode of faulting, and possibly of folding, occurred near the end of Pliocene time. Basin and Range block faulting elevated the Grouse Creek Mountains and gave the range the structure of a horst. Since sediments of the Salt Lake formation and also of the Tertiary unidentified formation were raised almost to the crest of the range, faulting evidently began after their deposition. Although the region may have been mountainous in Pliocene time it appears likely that the mountains were not distributed as they are today since a small outcrop of the Salt Lake formation occurs isolated high in the valley of Emigrant Wash in Section 13, T. 9 N., R. 17 W. (See Plate I.) This outcrop is interpreted as a remnant of formerly more extensive cover in what is now an area of high relief.

Basin and Range faulting occurred in part along older fault planes. Younger faults which may cross the pluton, such as that in Section 1,

T. 9 N., R. 17 W., merge with older faults which do not. For this reason it is difficult to assign ages to the episodes of normal faulting. For the sake of simplicity the writer has spoken of the history of the southern Grouse Creek Mountains as though only two epochs of normal faulting occurred, one associated in time with the formation of the pluton, one with the Basin and Range disturbance. Actually, it seems more likely that faulting extended intermittently over a long time, perhaps throughout the Tertiary period, and there may have been successive movements along old faults as well as the formation of new ones from time to time during the period.

The lithology and attitude of the Salt Lake formation suggests that the faulting and vulcanism which characterized the Basin and Range province during the Tertiary continued until latest Pliocene in the Grouse Creek area. In late Pliocene time Basin and Range faulting elevated the present Grouse Creek Range and since that time the area has undergone little structural disturbance. Plate IV represents the structural evolution of part of the eastern border of Bovine Mountain along the line A-A' of Plates I and II. Frames (1) through (6) portray successively (1) folding, (2) thrusting, (3) normal faulting and formation of pluton, (4) faulting, (5) Basin and Range faulting, and (6) erosion to the present level.

ECONOMIC GEOLOGY

Three types of possibly economic mineralization can be recognized in the Southern Grouse Creek Mountains.

(1) Tungsten mineralization occurs in a few places at or within 200 feet of the contact of the pluton with calcareous rocks. The area has been a small shipper of tungsten ore since World War I. Three localities account for most of the production: (1) the "Associated Mineral Works" (A. S. M.) mine west of Willow Wash, (2) the Magnitude Mine in Willow Wash and (3) the A & W Mine near Rocky Pass. Only the Magnitude Mine is held as a patented mining claim.

At the "A. M. W." and Magnitude mines the ore mineral, scheelite, occurs as small crystals and nuggets in the altered limestone and chloritic quartz diorite in fault zones of considerable local complexity. Hess and Larsen (1921) describe the minerals in the ore zones of the Magnitude Mines as, "pale yellow-green epidote, the larger crystals of which have flesh-colored centers, quartz, calcite, chlorite, actinolite in minute radial masses, and gray mica. Accessory minerals are scheelite, galena rich in silver, vanadinite, wulfenite(?) and stolzite. Some bismuth is reported to have been found." At the A & W mine the ore also occurs in minute crystals and nuggets in a sheer zone paralleling the limestone-pluton contact. It is suggested in a later section that the concentration of scheelite around the margins of the pluton may represent the "geochemical cumulation" of tungsten in the sense of Reynolds (1946).

(2) Very weak copper mineralization is sparcely present in many localities in and around the pluton. The copper occurs as malachite and, possibly, in small amounts as brochantite. It is concentrated in fault zones in the sedimentary country rock, occurring as staining in and on limonitic fault breccia. No copper mineralization was found in the pluton, although at Devil's Playground small streaks of green calcite resembling malachite were found. The streaks are 4 or 5 inches long, one or 2 inches wide, and 1/8 inch thick. They occur sparsely on the weathered surfaces of boulders of disintegration. Qualitative test for copper (addition of NH_4OH to a solution of the mineral in HNO_3 and also the potassium mercuric thiocyanate test) showed that no copper is present in the green calcite.

(3) The quartz-pyrite veins which give the red quartz monzonite its characteristic color are suggestive of hydrothermal activity. They occur over a wide total area (approximately 2 square miles). Locally, as in Section 14, T. 9 N., R. 16 W., the mineralization is intense. Since iron was undoubtedly introduced it is possible that other metalic elements were also carried by the mineralizing solutions. However, no evidence of this was found during the mapping of the pluton. Possibly

metals other than iron were carried by the hydrothermal solutions but precipitated at a lower level in the earth's crust, in which case the pyrite veins represent a capping of an economic mineral deposit. However, in many mining districts in the Basin and Range province (Bingham, Tintic), sercite and other silicate minerals were also introduced hydrothermally during the period of alteration in which the ore deposits were formed. In the red quartz monzonite there is little indication of this type of alteration. In the opinion of the writer, the lack of hydrothermal alteration except in the form of the quartz-pyrite veins argues strongly against the existence of economic mineralization at depth in the southern Grouse Creek Mountains.

ORIGIN OF THE PLUTON

General Statement

A review of the literature dealing with granitic rocks shows that there is very little agreement on their origin. The reason for this is that, presumably, granitic rocks are of plutonic origin and are the end products of a process which has stopped and cannot be directly observed. Unlike organic evolution, the genesis of granitic rocks does not leave clearly diagnostic fossils. The origin of the rocks must be deduced from (1) their geologic setting and internal features supplemented by (2) reasonable assumptions regarding their environment during formation and (3) the probable results of such an environment on silicate systems. Different petrographers have chosen different reasonable assumptions regarding environment and, consequently, have proposed different mechanisms to account for the origin of granitic rocks.

Two basic mechanisms have been proposed. The most widely currently held is melting, which produces molten rock matter called magma, and according to the magmatic theory the solidification of magma produces granitic rock. In contrast, transformist theory holds that the basic mechanism of granitic rock formation is replacement (metasomatism) of preexisting rocks, below their melting point, by the introduction and removal of appropriate elements. One or the other theory is generally called upon to explain the origin of particular plutons, although eclectic combinations of the two are also employed.

The present writer is opposed to the hypothesis that apparently identical rocks can form through different processes. It seems more reasonable and conservative to suppose that different environments will result in the formation of recognizably different rocks. If this principle is not valid then the ultimate aim of the petrologist, to deduce the natural history of rocks, is unattainable. Fortunately, the magmatic and transformist theories entail different consequences and it should be possible, at least in principle, to decide between them in a particular case. The writer proposes to examine the origin of the Grouse Creek pluton using as a guide the assumption that either the magmatic or the transformist theory is exclusively correct.

Criteria of Magmatic and Replacement Origin

Goodspeed (1948) has listed 21 criteria which in his opinion may enable one to recognize and distinguish between magmatic and metasomatic rocks. These are outlined below in order to facilitate their comparison with the features of the pluton described above. In the outline are listed the features expected of magmatic rocks only; their opposites or absence are the features expected of metasomatic rocks.

Goodspeed's (1948) Criteria of Magmatic Rocks

1. Form of pluton compatible with mass flowage of magma, either by injection or stopping.
2. Progressive increase in grain size from margins inward.
3. Clear and well formed phenocrysts.
4. Vesicular structures near borders.
5. Deuteric alteration.
6. Flow structures.
7. Contraction or consolidation jointing.
8. Gradation between differences in texture and composition.
9. Sharp walls.
10. Apophyses of similar composition to main mass.
11. Uniform pattern in over-all texture (on scale of inches).
12. Early-formed minerals anhedral; phenocrysts enhedral.
13. Included crystals in minerals are the early-formed ones and show sharp boundaries with their hosts.

14. High temperature forms, such as sanidine, may be present; the low temperature forms are deuteric.

15. On microscopic scale borders show sharp boundaries, flow structure may be present, deuteric alteration may extend into walls.

16. Xenocrysts and xenoliths show reaction rims.

17. Cognate inclusions indicate early magmatic phase.

18. An unusual accessory in diverse rock types may indicate magmatic consanguinity.

19. Variation diagrams may show trends in magmatic differentiation.

20. Trace elements different in pluton and walls.

21. Accordance of the mineral assemblage with the physio-chemical theory of magmatic origin.

Applied to the Grouse Creek pluton, it is evident that five criteria are satisfied (5, 8, 10, 11), nine are not (2, 3, 4, 6, 7, 12, 14, 15, 18), and seven may or may not be satisfied, since they depend either on information which was not obtained in the course of the study (16, 19, 20) or on the viewpoint of the investigator (1, 13, 17, 21). However, such an apparently simple criterion as (2) has been disputed by implication by Kennedy (1955), who proposes the hypothesis that granitic magma consolidates from the inside outward, driving out fluxes. If this is the case the borders of magmatic rocks should be coarse-grained due to fluxing and slow consolidation. The borders of the Grouse Creek pluton are in some places fine-grained, in others coarse-grained, and in most places show no increase nor diminution of grain size. To the present writer it appears that Goodspeed's criteria are inapplicable to the Grouse Creek pluton.

Other petrologist (cf. Grout (1948)) have suggested similar criteria by which magmatic and metasomatic rocks might be distinguished. Like those of Goodspeed, they do not give unambiguous results. Furthermore, there is no way of deciding which list, if any, is correct. To the writer there are very few criteria which strongly suggest magmatic origin, namely,

1. Glassy borders or interstitial glass would be considered conclusive proof of a cooled silicate melt and magmatic origin.

2. A border which is obviously a chill facies even if not glassy would be considered proof of magmatic origin.

3. A mineral or mineral assemblage indicating former temperatures above 600° C would be considered strong evidence supporting magmatic origin.

4. Features predicted by classicial magmatic theory, such as gravitative differentiation, would be considered strong evidence of magmatic origin.

5. Texture resembling that of an extrusive porphyry would be considered strong evidence of magmatic origin.

6. Structures which could be proved to be due to flowage would be strong suggestive evidence of magmatic origin.

7. Vessicles would be considered strong suggestive evidence of magmatic origin.

8. Doming or dilation structures would be considered suggestive evidence of magmatic origin.

On the other hand, the absence of such features in a rock would suggest to the writer possible replacement origin, and the suggestion would be strengthened by finding,

1. Obvious ghost or relict structures.

2. Textures resembling known replacement of recrystallization textures would be considered strong evidence of replacement origin.

3. Irrefutable textural evidence of replacement.

In the absence of these features the writer would consider evidence based on laboratory studies, such as the amount of albite disolved in orthoclase (cf. Tuttle and Bowen (1948)), suggestive evidence for or against replacement origin. However, in the opinion of the writer, it has not yet been proved that data from synthetic "granites" are strictly comparable to data from natural rocks.

Structural Setting

The Grouse Creek pluton is located in an area of folded, faulted and shattered sedimentary rocks. In this connection five observations may bear on the origin of the pluton.

1. The faults are largely pre-pluton since it is traversed by few faults.

2. Folding and overturning of the sedimentary rock is most intense one mile distant from the border of the pluton. The contact rocks are tilted but not folded or overturned.

3. In two localities, the west side of Emigrant Wash and the west side of the largest outcrop of red quartz monzonite, the location of pre-existing faults apparently influenced the location of the border of the pluton.

4. The border of the pluton is parallel to the strike of the contiguous sediment in a sufficient number of localities to suggest some control by the sedimentary rock over the location of the contact.

5. The dip of the sediments at the contact is neither predominantly away from nor toward the pluton.

The relative age of the pluton and faults favors niether the magmatic nor transformist theory since the intrusion of magma might be expected to produce faults, and some varieties of transformist theory might require faults as conduits for metasomatizing solutions. That the sediments are most intensely folded at some distance from the pluton is interpreted by the writer to suggest that the folding is not directly connected with the formation of the pluton. Either emplacement of magma or metasomatism might be influenced by structures such as faults or bedding. The dip of many of the contact sediments toward the pluton, however, indicates that doming was not a factor in its formation; the formation of the pluton was essentially passive.

It is the opinion of the writer that the intrusion of magma should entail some doming. Known magmas, i. e., lavas, having the composition of quartz monzonite are notably viscous. There seems no reason to suppose that granitic magma at depth is less viscous than its surface counterpart, unless either it is extremely hot or the magma is well fluxed with volatiles, principally water. Absence of high temperature minerals such as sanidine, and high temperature mineraloids, such as glass, suggests that the temperature of formation of the pluton was not high. The writer believes that the well known lack of water in deep mines, the evident geochemical concentration of water above the lithosphere and the paucity of hydrous minerals in granitic rocks indicates that granitic magma at depth is low in water. Granitic magma at depth should therefore be viscous. If granitic magma is viscous its intrusion should involve pushing aside, that is, doming of the contact rock. Since doming has not occurred the structural setting of the pluton is considered by the writer to be evidence in favor of transformist theory.

Size

The stock has an exposed area of about ten square miles and a maximum dimension of eight miles. Presumably if its margins were not in part blanketed by Cenozoic cover its dimensions would appear somewhat larger, but the actual exposure surely indicates the order of magnitude of its size in a horizontal plane and a suggestion of the third dimensional magnitude. One may adopt the assumption that the section of the stock exposed by erosion is possibly an average or random section. If this is actually the case, then the depth of the stock should be on the order of half the largest dimension of the stock exposed in the horizontal plane, namely, five miles, more or less. This is a condition which may be testable by geophysical means.

Finding a floor of the stock geophysically might be difficult since by hypothesis it would be in the Precambrian basement. One would be obliged to distinguish between granitic rock and crystalline schists with perhaps gradational contacts between the two. However, much of the contact might be sharp and marked by a distinct physical hiatus, in which case a geophysical survey might determine a floor of the pluton.

Finding a fairly shallow floor of the stock would strengthen the hypothesis that the pluton is a product of replacement because such a shallow floor probably would not exist according to magmatic theory, although the pluton could be a lopolith. Unfortunately, failure to find such a floor would indicate either that the means used to detect it were insufficiently delicate or that the assumption that the pluton is floored is erronious.

Shape

The stock is irregular in outline, with embayments and projections which make it rudely cruciform. This fact in itself appears to have no genetic significance. However, if the pluton is also irregular at depth finding its borders by geophysical means might be very difficult, even if the borders are sharp. It might be, though, that the gross shape of the pluton could be determined and be shown to slope at depth either toward or away from its surface borders. If at a depth of three or four miles the borders slope outward this would be considered by the writer as evidence favoring the magmatic hypothesis. Conversely, if at depth the borders slope inward, this would be evidence favoring the transformist hypothesis.

Constituent Phases

The most striking large scale feature of the stock is its overall mineralogical uniformity. The supposed mechanism through which it originated must therefore be capable of producing homogenous rock.

Petrologists of the magmatic and transformist schools generally see no difficulty in the formation of homogenous rock either by melting or by replacement. The proponents of each theory recognize supposed defects in the other, but for the purpose of this paper it is assumed that homogenous rock can be produced by either mechanism. More detailed examination of the Grouse Creek pluton shows inhomogeneities which are more difficult to explain. Foremost is the division of the stock into four distinct phases; lesser inhomogeneities are discussed in later sections.

Red Quartz Monzonite

Neglecting the iron staining and quartz veins, there are differences between the red and the gray quartz monzonites which are listed on page 71 . These differences are less than those between the gray quartz monzonite at Devil's Playground and in Sections 1, 2, 11, and 12, T. 9 N., R. 16 W., described on page 50. Except for the iron staining and veins the two phases are therefore the same. The veins of quartz and the pyrite mineralization are probably related genetically because the most intense pyrite mineralization always occurs in the quartz veins and diminishes in intensity away from them. This association in space strongly suggests to the writer a genetic association in time. Since the veins cut the quartz monzonite and the staining envelopes its constituents, the veins and staining are later than the plutonic rock. The origin of the red quartz monzonite is therefore the same as the gray with the added complication of younger veins.

The quartz veins and pyrite mineralization probably are due to hydrothermal solutions. As pointed out by Bateman (1950) the mineral deposits around hot springs suggest that many veins composed of quartz and sulfide minerals were formed by the action of hot waters, and this inference is strengthened by studies of the composition and internal vapor pressure of liquid inclusions in the vein quartz. Bateman further suggests that the source of the hydrothermal solution is water exolved from consolidating magma. Such an origin would imply, in the case of the Grouse Creek pluton, that the succession of events was (1) intrusion of magma, (2) consolidation of the borders of the magma mass, (3) minute shattering of the consolidated rock to provide conduits for the hydrothermal solutions, and (4) ascent of the solutions with concommitant recrystallization of the plutonic rock along the vein channel-ways and deposition of pyrite. The iron in the pyrite was probably later disseminated in the pluton as hematite and limonite by the action of ground water. This sequence of events satisfactorily explains the veins if the first step, intrusion of magma, is admitted.

If intrusion is not admitted a very similar sequence of events in which hydrothermal solutions derived from connate or even juvenile water are assumed to have traversed the pluton also explains the veins. In either case the veins and pyrite mineralization contribute little to the question of the origin of the pluton.

Gray Quartz Monzonite

The gray quartz monzonite lacks those features which the writer believes would clearly indicate magmatic origin. However, assuming both melting and replacement could form the rock which makes up 75% of the pluton, the cognate inclusions and the areas of rock with granitic intergranular texture in the quartz monzonite require explanation.

Cognate inclusions can be explained by the magmatic theory in one or both of two ways. Inclusions may represent an early chill facies. According to Bowen's reaction principle (Bowen (1928)) the first minerals to form from a cooling silicate melt are the basic ones. If these form as a chill zone and are later engulfed by granitic magma they would not be absorbed but would remain as distinct inhomogeneities, perhaps sinking in the lighter magma (Grout (1932)). This explains why the inclusions are concentrated near the border of the pluton but does not explain the gradation between the inclusions and surrounding rock. If such a mechanism operated one would expect to find (1) remnants of the early-formed chill zone in some places at the contacts, and (2) a later basic chill zone representing the magma which swept away the early-formed chill zone. Since these features are lacking in the Grouse Creek pluton it is assumed by the writer that the cognate inclusions are not part of an early chill facies.

It could also be supposed that the basic inclusions are entrained from depth by the ascending magma. However, since the magma must have been passively intruded it must have moved slowly. If it moved slowly the heavy inclusions would have sunk, i.e., would not have been entrained. Therefore it seems to the writer unlikely that the inclusions came from depth. If the inclusions cannot be attributed either to deep-seated or shallow magmatic mechanisms then they are not magmatic. If the inclusions are not magmatic it seems unlikely that the gray quartz monzonite is magmatic, since there appears to be a complete gradation in composition and texture between the basic inclusions and the quartz monzonite.

Reynolds (1946) proposed a replacement hypothesis which, very slightly modified, appears to the writer to explain the inclusions. On the basis of the only available detailed chemical data on the border facies of granitic plutons, she proposed the concept of the "basic front." Very briefly stated, if sedimentary rocks are transformed to granitic rocks by replacement and recrystallization, calcium, magnesium and iron must be removed and alkalis and silica introduced. This is because in the average sedimentary rock Fe + Mg + Ca = 9.85%, whereas in quartz monzonite the corresponding figure is 5.57% (data from Johannsen and Leith and Mead). Ramberg (1952) suggests that Ca, Mg and Fe tend to sink in the earth's crust during the formation of granitic rocks. Reynolds' hypothesis is that they may be in part pushed outward from the transformed sedimentary rock and frozen in position as a "basic front" of dioritic composition. The present writer proposes, following Reynolds, that the cognate inclusions are remnants of a basic front, fossil relics of an earlier stage in the transformation of sedimentary rock to quartz monzonite. Such an origin would explain the gradation between the inclusions and the surrounding rock. It would also accord with the fact that the inclusions are most numerous near the border of the quartz monzonite and particularly numerous in the transition zone between the quartz monzonite and the quartz diorite. It suggests that the basic rims found around some inclusions are minature basic fronts, and explains why the mineralogical composition of the inclusions is very similar to that of the surrounding quartz monzonite:

they are the same rock in slightly different stages of the transformation processes.

The areas of rock with granitic intergranular texture may be explained as products of one of three mechanisms. (1) They may be an intermediate form between aplite and quartz monzonite. (2) They may be relicts of quartz porphyry dikes which have been recrystallized and partially transformed to a rock of granitic texture. (3) They may represent relicts of a texture developed in a late stage of the transformation of sedimentary rock to quartz monzonite.

The characteristics that the patches of granitic intergranular rock share with aplite are the grain size of the intergranular material and the sugary texture of that material when it occurs in patches between the larger granitic grains. They do not have sharp boundaries like aplite veins and masses. Moreover, the fine-grained material occurs not only as patches and trains between granitic grains but also within the granitic grains, as though the larger grains have enveloped the smaller (or the smaller had grown within the larger). The texture has the appearance of a replacement. If one believes aplite veins to be magmatic then it seems unlikely that the patches of granitic intergranular rock are intermediate between aplite and quartz monzonite. If one believes aplites to be recrystallization or metasomatic products then from the physical features of the patches one might believe them to be intermediate. However, because aplites are generally very sharply defined inhomogeneities in pluton, whereas the patches have very indefinite borders, it seems unlikely to the writer that the agents causing the one would also cause the other.

In some respects the granitic intergranular rock resembles granite porphyry. It differs petrographically from granite porphyry in having (a) a very attenuated"groundmass," (b) typical granitic and even granitic slightly porphyritic texture of the large grains, and (c) absence of corroding of the large grains. In addition, the large grains include more of the smaller than is usual in a prophyry. The writer considers these differences sufficiently large to suggest that the granitic intergranular rock is not recrystallized granite porphyry, but is also influenced in this opinion by the fact that no porphyry dikes are known to occur in the Grouse Creek pluton.

The patches of granitic intergranular rock resemble most closely some of the border facies of the pluton. Anticipating the discussion of border textures the range in grain size is regarded by the writer as suggestive evidence of replacement. That the patches with a wide range of grain size occur isolated within the normal quartz monzonite is regarded as evidence that they are relicts, much like the basic inclusions.

The writer believes they represent a late stage in the transformation of sedimentary rock to quartz monzonite because the basic inclusions suggest that transformation has taken place, as indicated above, and the composition of the patches is close to normal quartz monzonite.

Quartz Diorite

The quartz diorite is gradational with the quartz monzonite and inclusions of diorite occur in the monzonite. Because of this relation it is thought by the writer that the two are probably closely linked genetically and that the quartz diorite is older than the quartz monzonite. This would be the case if the quartz diorite were an early magmatic injection, as are the tonalites of the batholith of southern California (Larsen (1948)). If the basic rock were an early injection, however, one would hardly expect to find it disseminated as inclusions throughout the quartz monzonite, nor in gradational contact with it. Furthermore, one might expect to find veins of the quartz monzonite in the quartz diorite, but one does not. It appears to the writer that the hypothesis that the quartz diorite is an early injection involves contradictions with conventional magmatic theory. The hypothesis that the quartz diorite, like the inclusions, represents a basic front seems to involve no contradictions. Its features are those one would expect of a basic front.

In addition, the noticibly high tenor in rutile suggest that were a detailed chemical study made a "geochemical culmination" in titanium might be found, in accordance with the extended hypothesis of the basic front proposed by Reynolds (1946).

Chloritic Quartz Diorite

The chloritic quartz diorite borders the quartz diorite, is gradational with it and is not found where the quartz diorite is absent. The two seem therefore related in origin. Rocks of the type mapped as chloritic diorite are generally not considered magmatic but are regarded as contact effects attending the intrusion of magma. Speaking of the contact rocks associated with ore deposits, Weed (1903) apparently summarized traditional petrologic thought when he said that, "The conversion to garnet-epidote-calcite, etc., rock was complete before the consolidation of the igneous rock." This makes the contact rock and the igneous rock roughly contemporaneous, which appears true in the Grouse Creek Mountains largely for lack of evidence to the contrary.

One variant of the chloritic quartz diorite phase, described in some detail on page 96 ff., might bear on the relative ages of the chloritic diorite and the rest of the pluton. Irregular to rounded masses three to 15 mm long and resembling fine-grained granodiorite occur in an aphanitic matrix of quartz, feldspar, epidote, chlorite and calcite.

It could be argued that the granodioritic masses represent a former granitic rock which has been largely broken down and recrystallized by metamorphism. However, so far as could be seen the rock does not grade laterally into granitic rock and no granitic rock is exposed within 1000 feet of its outcrop. For this reason the writer considers that, insofar as one is guided solely by the evidence, the variant must be considered the same age as the rest of the pluton. Applying the theory of the basic front to the chloritic quartz diorite it appears that it may be part of the advance facies of the front and that possibly the tungsten mineralization which is present locally in the chloritic diorite represents the geochemical culmination of that element.

Borders

The border facies of the Grouse Creek pluton exhibit the greatest variation in composition and texture. Although much of the border is composed of normal quartz monzonite it is in the vicinity of the border that one finds very coarse-grained facies (as at North Rocky Pass), fine-grained facies (as at the Compressor mine), quartz porphyry facies (as in Section 1, T. 9 N., R. 17 W.), and granitic and granodioritic facies (as at Citadel Peak). The chloritic diorite appears to be a contact facies of the quartz diorite, and in a broad sense the quartz diorite is a contact facies of the quartz monzonite.

There appears to be no reason to believe that the contact facies are not contemporaneous in origin with the large mass of the pluton. Lacking evidence to the contrary, it seems logical to assume that both the large mass of the pluton and its contact facies originated together. Since there is a difference between the principal quartz monzonite and some of its border facies there must be a difference in the agents which produce the two. The difference could be in kind or degree. It appears to the writer to be a more modest and conservative assumption that the differences are ones of degree. If this is the case then the interior of the pluton represents the thoroughgoing action of the agents which produced it, whereas the borders represent their weaker action. Adopting this viewpoint, the interior of the pluton represents either thorough fusion or recrystallization whereas the borders represent in places only incomplete fusion or recrystallization.

It was mentioned above that the pluton and its margins lack those features which the writer would consider evidence of fusion, and therefore the writer believes the pluton due to replacement and recrystallization operating simultaneously (metasomatism). The diversity of some border facies suggests that these two agents operated incompletely near the borders of the pluton, and in so doing produced the varied rock types.

The writer attempted to arrange the border facies into a series which was hoped might show how metasomatism effected the sedimentary country rock. It was thought that possibly a sequence of rocks in space might reflect a sequence in time. It was found impossible to construct a series which could be interpreted in this way. From this negative evidence the writer believes two generalizations may be drawn with regard to the Grouse Creek pluton. (1) Those textures usually explain by appeals to special features of magmatic crystallization - myrmekite, micropegmatite, perthite - are most conspicuously developed around the borders of the pluton and are indicative of incomplete development of the granitic texture. (2) Incomplete transformation or metasomatism is characterized by an extreme range in grain size, both on a macroscopic and microscopic scale. On a macroscopic scale the range in grain size is from very coarse- to very fine-grained facies, and on the microscopic scale the range is on the order of that of a quartz porphyry or of the rocks of granitic intergranular texture.

Texture

A review of the literature on the origin of plutonic rocks shows that their textures are among their least understood features. No satisfactory theory has been advanced to explain the granitic texture, and none emerged from the mapping of the Grouse Creek stock. It appears likely that a satisfactory theory of texture awaits further advances in the domains of physical chemistry and solid state physics.

Without any assumptions regarding the fundamental causes for the observed textures, some inferences may be made concerning the origin of the pluton by comparing its textures with those of bodies whose origins are known or presumed known. Such reasoning by analogy is safe if texture is, in the words of Mill (1850), a "material relation," and if the analogous body is truly comparable. It will be assumed that texture is a material relation that other rocks are comparable bodies.

The texture of the Grouse Creek pluton clearly does not resemble that of any rock known to be magmatic. The granitic texture does, however, resemble that of known precipitates, the limestones. From this analogy one might conclude that the plutonic rock of the stock consolidated as a precipitate, in conformity with magmatic theory. This would be wrong. The texture of limestones, holocrystalline, allotriomorphic, equigranular, stems not from their being precipitates but from the diagenetic changes they have undergone since deposition, changes due to recrystallization carried out in the solid state or with the intervention of pore solutions. Pressing the analogy, therefore, the texture of the pluton is a recrystallization texture, although perhaps the texture of a recrystallized magmatic rock.

Likewise, the texture of the pluton does not resemble the clastic texture of a sandstone but it does resemble the texture of the Eureka(?) quartzite in the vicinity of the stock (except where the texture of the quartzite is granulitic). The quartzite is evidently not magmatic and nor is it a precipitate; its texture is derived by recrystallization of the equant quartz grains of which the original sandstone was composed. In the immediate vicinity of the pluton the texture was further modified by metasomatism which subtracted silicon and introduced the elements now represented by feldspar biotite and chlorite. The form of the "feldspar network" which replaces the quartzite is irrefutable evidence of metasomatism (see Fig. 10). It is precisely in this zone that the texture of the pluton and the texture of the quartzite are indistinguishable.

The granitic and granitic intergranular textures of the pluton do not diverge strongly from those of ores of undoubted metasomatic origin (cf. Lindgren (1932). pp. 173-187 and Bateman (1950) pp. 155-156). The comparison is the more striking when one recalls that the criteria developed to identify replacement deposits are largely those shown by bodies in which replacement is incomplete, in contrast to granitic bodies which appear to be much more thorough replacements of the country rock. Be cause the texture of the plutonic rock does not resemble that of known magmatic rocks, and because it does resemble that of rocks thought to be recrystallized or metasomatic, it is inferred by the writer that probably the plutonic rock is also metasomatic.

Sedimentary Inclusions

The sedimentary inclusions are a puzzling feature of the pluton irrespective of how it was formed. That some carbonate inclusions should be silicified whereas others show no metamorphic effects apparently depends upon subtile controls of contact metamorphism. Possible factors which might facilitate or hinder replacement of sedimentary rock are chemical and mineral composition, grain size, porosity, and relation to faults or other conduits of metasomatizing solutions. How these factors operated in the Grouse Creek Mountains is unknown because due to the extensive faulting it is not possible to correlate inclusions with definite horizons in the surrounding sediments. It is therefore not possible to study the corresponding altered and unaltered rocks. It is an observational fact that those carbonate inclusions which are apparently unaltered are dolomite, but the former composition of those which are altered could not be established. Regardless of the origin of the pluton, however, the altered sedimentary inclusions are probably due to metasomatism during the formation of the pluton (cf. Grout (1937) and Reynolds (1946)).

Dikes

It has been observed that carbonate formations often enclose carbonate veins, that quartzite formations enclose quartz veins, and that granitic bodies enclose granitic veins (aplite and pegmatite dikes). It seems reasonable to attribute to all these a common origin. Particularly, it is difficult to understand the reasoning of Reynolds (1943), who says,

> That some magma was indeed formed is evidenced by the existence of aplite veins. Being composed essentially of microcline and quartz, the aplites represent that portion of the granodiorites which, with rise of temperature, would become fluid first. (p. 233)

The aplite and pegmatite dikes of the southern Grouse Creek Mountains show those features — porphyritic texture, myrmetite — which were found elsewhere are taken as evidence of replacement. They also show, in rare instances, transverse structures already described which appear to be evidence of movement of their walls during a late stage in their formation. The common association of aplite with pegmatite is another manifestation of the large range in grain size which characterize replacement textures during their formation. Evidently whatever the factors which cause the development of small grains during recrystallization, they are very similar to those causing the development of large grains, because the two are so often found together.

The attitudes of the aplite dikes in the vicinity of Rocky Pass were plotted in stereographic projection and it was found that they have no marked preferred orientation. Seen in the field in conjunction with the joints, they resemble them in the manner in which they lack persistence along strike. They appear to have originated by replacement at depth along zones of slight movement or merely, perhaps, of low pressure. The curious rounded pegmatitic inclusions found west of Rocky Pass seem to be similar to pegmatite dikes except in form. They show that local and isolated fluctuations or inhomogeneities in the conditions of formation of the pluton may lead to large variations in texture, an observation which was made by Ramberg (1956) in connection with the pegmatites of Greenland.

Conclusions

In the opinion of the writer the evidence of the field and of the laboratory supports the theory that the Grouse Creek pluton represents transformed country rock. The evidence, however, is suggestive and not conclusive. The most that can be said categorically is that many features one would expect were the pluton magmatic are lacking and those one might expect were it metasomatic are present.

The voluminous literature on the origin of granite testifies that geologists cannot reach a consensus on this question in the way that sedimentary petrologists have reached a consensus on the origin of sandstone. This suggests that geologists are not seeking the facts which could resolve the question. That this might be the case was hinted by Jahns (1948) when he said, "The accumulation of detailed data from individual granite masses may appear to be like pouring molasses down a well. . . ." In the opinion of the present writer he drew from this premise an incorrect conclusion when he went on to say, ". . . yet it is only by the collation of data of this sort that we can expect to move ahead toward some settlement of the quantitative relations involved in the main question," because it implies that apparently indistinguishable granites are produced by processes basically as different as fusion and replacement.

Conventional field mapping, conventional petrography and laboratory investigations seem inadequate to determine the origin of granite categorically. Thermodynamic reasoning apparently may be used to support either the magmatic or transformist school (cf. Turner and Verhoogen (1951) and Ramberg (1952)). However, Reynolds (1952) and Tuttle and Keith (1954) may have opened new avenues of investigation by concentrating on significant minor features of plutonic bodies, although from the same kind of evidence they come to radically opposed conclusions. Tuttle and Bowen (1958) have also described highly suggestive results of their work on the phase relations of the mineral components of granite, and Slawson's (1958) determinations of the lead content of feldspar in certain Basin and Range province plutons may have an important bearing on the origin of granite.

The minor features of granitic bodies may be those which petrologists have been overlooking (none were investigated in the Grouse Creek pluton) but which may hold the key to the granite problem. The writer feels the major features of the Grouse Creek pluton do not reveal its origin unambiguously. There are other features, more or less difficult to determine, which together might provide data from which a convincing theory of origin could be deduced. Ten such features are enumerated below, but the number of conceivable pertinent ones is very large and the labor of determining them enormous.

(1) The distribution and variation of the elements which make up the pluton and the surrounding sediments undoubtedly are germane to its origin. If the elemental composition of the pluton and surrounding sediments were known the data could be plotted on a contour map. Such a map, or its first derivative, might show significant concentrations of

elements, such as potassium, arranged zonally or possibly could deliniate relic structures which otherwise might be unobserved. Conversely, the lack of such chemical zonation or structures would be significant in any theory of origin of the pluton.

(2) The distribution and variation of the chemical constituents of particular minerals in the pluton might provide information concerning the evolution of mineral species. Such would be the case if it were found, for example, that the K:Na ratio in the orthoclase varied from the center of the pluton outward toward its margins.

(3) Knowledge of the gross and detailed fabric of the pluton might show correlation between types of fabric, mineral compositions and elemental distribution as well as enhance the knowledge of the structure of the pluton. It is conceivable that detailed study would show that certain variations in composition are associated with certain types of fabric, and that by plotting fabric one would be saved the burden of determining some types of compositional variation.

(4) Determination of the complete mineralogical composition of the pluton, including the chemical composition and distribution of those minerals such as xenotime, garnet and tourmaline which are not ordinarily seen in thin section, might deliniate structures or trends not otherwise observable. If such determinations were continued in the

surrounding sediments they might reveal that the pluton is a source or sump for certain minerals, or that the influence of the pluton extends far beyond the usually observed limits of contact action.

(5) It might be found that determination of the inversion temperature of quartz, using the method of Tuttle and Kieth (1954) would reveal significant trends within the pluton, or that comparable or divergent results are obtained using the methods of Reynolds (1952) to determine the optical character of the feldspar throughout the pluton.

(6) The kind and amount of perthite, or fluid inclusions in quartz, or trace elements in biotite, might be related to the local history of parts of the pluton and could possibly reveal information which would be useful in deducing the origin of the pluton as a whole.

(7) Minute mapping of border localities, including those at which the pluton apparently abuts abruptly without contact effects upon the surrounding sediments, might yield information on the transformations which sedimentary rocks undergo in the vicinity of plutonic rocks. If the determination of high or low feldspar and quartz were made across the border it might be possible to determine how the physio-chemical conditions varied from within the pluton to within the sedimentary rock during the formation of the border facies of the pluton.

(8) Mapping selected aplite and pegmatite veins spectrochemically, petrographically and structurally might reveal whether or not they are composed of locally derived material (i. e., are recrystallizations of the wall rock) or whether they are composed of material derived at some distance from the veins.

(9) It might be possible to determine the relative ages of various portions of the pluton and thus determine how long it took to form the pluton and its constituent parts.

(10) The zircon rounding index of the mineral from the pluton might be compared with the index of zircon from the nearby rhyolites. A similar index would be suggestive of a similar origin, but it might be found that the rounding index would vary from place to place in the pluton and be correlative with other features.

If the features of the Grouse Creek or any other pluton were to be mapped following the above or a similar list, one would possibly know enough about it to errect a convincing theory of origin. The work involved in such a mapping program would be large, but no more than is now spent in determining the apparently undiagnostic features of numerous plutonic bodies throughout the United States and the special features of unrelated plutons which cannot be effectively collated.

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